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TERMITES AND TERMITE CONTROL

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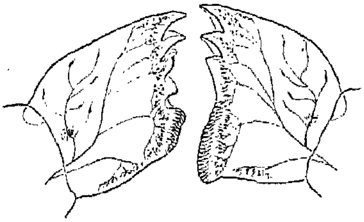

10635

BERKELEY
UNIVERSITY OF CALIFORNIA PRESS
1934

10635/36
IARI

University of California Press
Berkeley, California

Cambridge University Press
London, England

Issued January, 1934

PRINTED IN THE UNITED STATES OF AMERICA
AT THE UNIVERSITY OF CALIFORNIA PRESS
BY SAMUEL T. FARQUHAR, UNIVERSITY PRINTER

TERMITES AND TERMITE CONTROL

A REPORT TO THE TERMITE INVESTIGATIONS COMMITTEE

A discussion of the biology of termites, and an account of the termites of the United States, Mexico, the Canal Zone, the West Indies, Hawaii, and the Philippine Islands, with recommendations for prevention and control of termite damage by methods of construction and the use of chemically treated and unpalatable woods

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INTRODUCTION

BY

A. A. BROWN

THE ORGANIZATION of the Termite Investigations Committee followed the publication of the final report of the San Francisco Bay Marine Piling Committee in 1927, and is in many ways a development from the work of the latter organization. The personnel of this Committee in its earlier stages was largely representative of the earlier group. Through years of cooperative effort and study of the complex problem of marine borers, the members, by experience, learned to turn to the scientists of our great State University for assistance in finding a solution.

My attention was first directed to the presence of termites in Crockett during the swarming season in the fall of 1927. Upon inquiry, Professor Charles A. Kofoid, of the University of California, stated that judging by the number of specimens of termites sent his laboratory from a large area of the state and extending through Arizona and as far as Texas, he thought it possible that we were experiencing a "flare-up" in termite activity.

At about this time *Coptotermes* were found nesting in large numbers in the woodwork of an ocean liner lying at dock on the San Francisco waterfront. Added to the apprehension of invasion was the agitation caused among home owners by the flood of termite operators, some of whom were not well informed as to the results of termite infestation and not over-careful about arousing unfounded fears on the part of their prospective clients. An informal discussion of the problems attendant on the possible introduction of *Coptotermes* into California was had with the management of certain interested corporations, and it was agreed that an effort would be made to raise a sum of money for research purposes, provided the cooperation of the University of California could be obtained. Upon inquiry, President W. W. Campbell expressed his approval of the undertaking and gave his assurance that the University would cooperate to the fullest extent.

Under date of May 10, 1928 an appeal for funds with which to organize the work of the Committee was made to corporations having their principal place of business in San Francisco. The notice stated:

> It is proposed to organize a "Pacific Coast Committee on Termite Investigations" to investigate the conditions as they exist in the region pertaining to termites, their action upon structures, the best means of protecting these structures against their attack, and to prepare progress reports as the work progresses.
>
> This work is being instigated on account of the ravages of termites, which are becoming increasingly destructive, and if possible to pre-

> vent the introduction to the Pacific Coast of the more destructive oriental termites. There has never been a comprehensive study made of termites on the Pacific Coast and it is imperative for the good of existing structures that this study should be made, as communities heretofore immune to the attacks of termites are now becoming infested. This work is to be done under the direction of a committee comprised of a representative from each of the principal contributors and the Advisory Council of the University of California. Professor C. A. Kofoid and Professor S. F. Light will direct the biological work.
>
> It is estimated it will require an expenditure of $10,000 a year and will take at least three years to complete the study of the biological phase of all termites, the various kinds of chemical protection, and the best methods of construction, which the Committee is planning to undertake.

With the very valuable assistance of the late president of the California and Hawaiian Sugar Refining Corporation, Ltd., George M. Rolph, a fund of $30,000 was soon subscribed.

The preliminary organization meeting was held in the Board Rooms of the Board of State Harbor Commissioners, in San Francisco, on August 6, 1928. It was soon discovered that the problem confronting the Committee was vastly more complicated and of wider importance than at first anticipated, necessitating the raising of additional funds, the total amount being $54,154. The list of subscribers is to be found on page xxv, and the committee organization on page xxiii.

This report is the result of this cooperative enterprise. Its contributions of data, ideas, conclusions, and criticisms are in large part the results of the cooperation, on the one hand, of men prominent in the large-scale production and utilization of wood, and, on the other, of scientific men, chiefly members of the faculty of the University of California at Berkeley, interested in specific phases of the subject. These two groups have worked in committees organized to provide convenient centers of communication and multiplied contacts, meeting jointly for progress reports and general conference.

The relations of the producer of lumber and its products to this investigation have been most advantageously and helpfully represented by Mr. A. C. Horner, in charge of the Western Office of the National Lumber Manufacturers Association, and Mr. Earl E. Bowe, Field Representative in that office and, during the last two years of the life of the Termite Investigations Committee, its Executive Secretary. Their knowledge of the lumber industry, of building practices and conditions, of structural details, and of the practical significance of termite damage, has been of greatest value in applying the biological and chemical findings to the needs of the architect, construction engineer, builder, and owner.

The engineering staffs and the principals of the cooperating corporations have made valuable contributions from their extended records of termite damage. Their personal experiences with the work of these insects have been of greatest value to the Committee in the accumulation of data, and of direct assistance to our field biologists and chemists in planning field experiments, and in the formation and criticism of our conclusions.

Specifically, the engineering staffs of the Southern Pacific Company, The Atchison, Topeka and Santa Fe Railway, the Standard Oil Company of California, the Pacific Gas and Electric Company, the Pacific Telephone and Telegraph Company, the California and Hawaiian Sugar Refining Corporation, Ltd., the San Diego Consolidated Gas and Electric Company, the Department of Building of the City of Pasadena, and especially the Southern California Edison Company, have contributed freely and extensively to the work in time, facilities, data, and discussion.

The cooperation on the part of the University of California at Berkeley, initiated by President W. W. Campbell, has been continued by the present incumbent, President Robert Gordon Sproul. The University has not only contributed the valuable services of eminent men of science, but has also provided laboratory space in which much of the experimental work of the Committee was conducted.

The Committee was particularly fortunate in having Professor Charles A. Kofoid undertake the direction of the biological phases of the investigation. His interest in the economic values of the biological sciences and their application in so complex a problem as this has proved of inestimable value.

We were likewise favored in having available at the University of California at Berkeley Professor S. F. Light, an eminent investigator of termites. He was already familiar with their destructive powers through his termite studies in the Philippine Islands and China.

The Committee also received the helpful cooperation of Professor A. E. Emerson, of the University of Chicago, and of Dr. T. E. Snyder, of the Bureau of Entomology, U. S. Department of Agriculture, in the initial stages of its program of investigation. Under the auspices of the Committee public symposia were held in Berkeley, Los Angeles, Pasadena, and San Diego, California, in which these visiting specialists joined with local members of the Committee in public discussions of the termite problem, as later published by the Committee (see Emerson, 1929*a*, *b*; Kofoid, 1929; Snyder, 1929*b*, *c*). These symposia were supplemented by local round table conferences for discussion of the Committee's program.

The authorship of the various chapters of this book indicates the person or persons primarily responsible for the preparation of the manuscript, although in a number of cases the data have been accumulated with the aid of many others, and the conclusions were reached only after discussions with many different observers, often with divergent points of view. This cooperation is indicated by authorship in only a few cases, and is of necessity omitted in all others.

This work is in the main the report of scientific investigations and technical advice. Statements in the book are made on the responsibility of the author or authors of the chapters in which they occur. Committee action involving approval of the authors' statements has not been taken, except that chapter 46, "General Recommendations," is published with the sanction of the Executive Committee.

The function of the Termite Investigations Committee, with its many subcommittees, has been directive, advisory, and supplemental mainly in service relations to the authors and others who have carried on the researches herein published. These investigators have profited greatly by this advice, but they have been free from Committee dictation in arriving at their conclusions.

The Editorial Board has reviewed the entire manuscript, and their suggestions, which, however, have been in no case mandatory, have assisted the various authors in the unification of this report.

As Chairman of the Termite Investigations Committee, I wish to acknowledge the many helpful suggestions contributed in the initial work attendant on launching the program. Had it not been for the wise counsel of Professor Charles A. Kofoid, Professor S. F. Light, Mr. W. H. Kirkbride, and our efficient Secretary-Treasurer, Mr. J. Walter Kelly, in shaping a practical program with an appeal to practical business leaders, it is doubtful whether the Committee would ever have matured. Obviously, it was necessary to have a program with a vital appeal if we hoped to promote the project. This volume is the result of our effort. It is never possible to complete a research program such as this one; by its very nature its scope widens as the work progresses. Others no doubt will add to it in the future.

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PART I

TERMITES AND THEIR BIOLOGY

CHAPTER 1

BIOLOGICAL BACKGROUNDS OF THE TERMITE PROBLEM

BY

CHARLES A. KOFOID

Termites are primitive insects related to cockroaches. Unlike these scavengers, the termites live a secretive life, feed primarily on cellulose, and are organized into colonies which are diversified into castes differing in structure and function. This social organization prolongs the period of immaturity, increases their destructive potentialities, and has accelerated the evolution of highly specialized instincts. These factors combine to raise the termites to a high level of efficiency among insects in general, and extend and accelerate their work as destroyers of wood and of cellulose throughout tropical and milder temperate regions.

Termites are commonly but erroneously called "white ants." However, not all species and castes of termites are white, and no termite is a true ant (chap. 32). While it is true that the vast majority of individuals in colonies of termites are white (fig. 1*c*–*f*), these are not usually visible unless dug out of their burrows in wood or earth. Other individuals of the same species, the winged forms called "alates," have black bodies and, usually, dark wings (fig. 1*a*), but these are only to be seen for a few brief hours at the swarming season, flying or emerging from wooden structures or the earth. The term white ant should therefore be abandoned, since it leads to serious misconceptions as to identity, habits, and methods of control of the insects properly named termites.

Economical and practical methods of preventing termite attack upon wood and its products must be based upon a knowledge of the habits and life histories of the particular types of termites causing the damage, and in some instances even of the particular species. The studies made by the Termite Investigations Committee concern themselves with three major types of termites, namely, the dry-wood, the subterranean, and the damp-wood termites. The results of these biological studies are recorded in detail in chapters 2–31 of this report.

The termites as a group are very ancient. Their nearest relatives are the cockroaches, from which, however, they have been distinct for many millions of years. Fossil termites of the very genus whose species are now doing damage all over the United States have been found in deposits known to be many millions of years old. They have lived for great periods of time on the wood furnished by forests, wooded canyons, oak groves, and numerous arid-

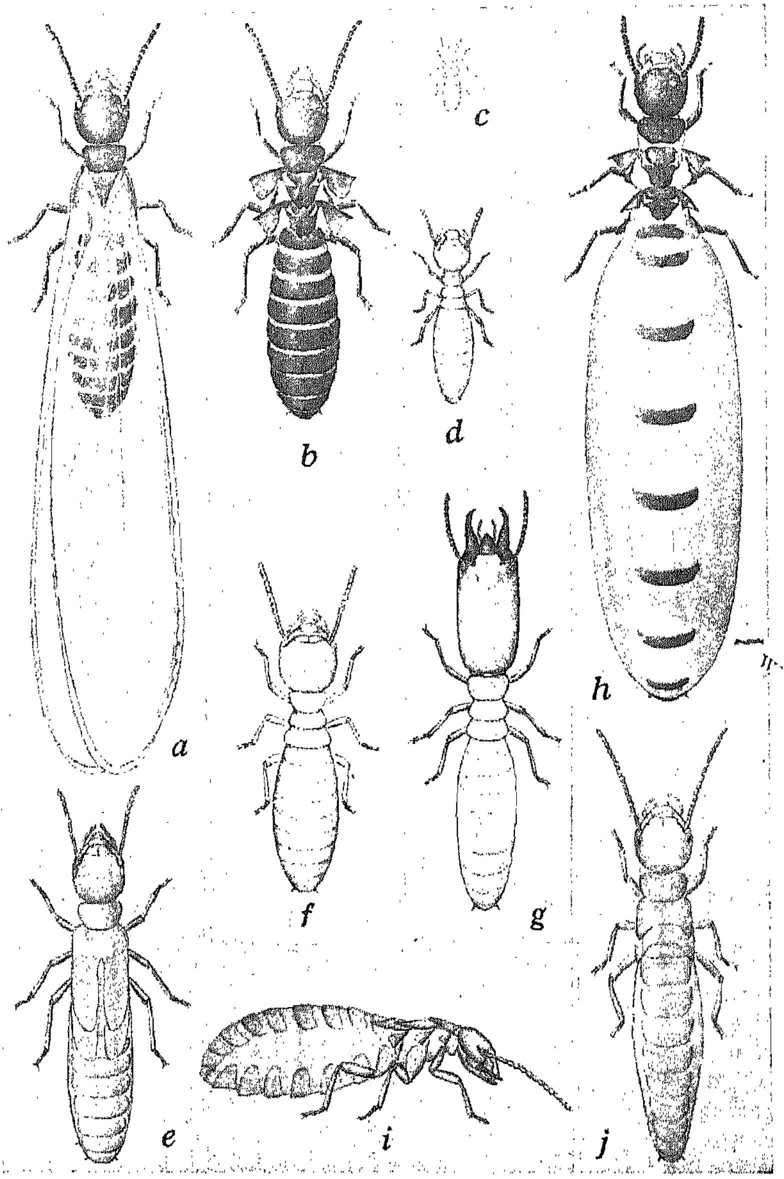

Fig. 1. The different castes and young, or nymphal, stages (instars) of *Reticulitermes hesperus*, the western subterranean termite. All drawn to same scale. × 9.

a. Winged reproductive, or alate, ready for swarming. This is the only form in which termites are commonly seen outside of their burrows. Males and females are very similar in appearance. *b.* Dealated reproductive whose wings have been shed after swarming. *c.* Very young nymph in first nymphal instar, or growth stage, not long from the egg: caste not yet evident. *d.* Middle-sized nymph, in third instar: caste still not evident. *e.* Late nymph of reproductive caste with wing pads, or immature wings. *f.* Individual of the worker caste, fully developed. *g.* Individual of the soldier caste, fully developed. *h.* Old breeding queen, enlarged, or physogastric. *i.* Short-winged, brachypterous, or second form individual of the reproductive caste, called a supplementary reproductive. *j.* Wingless, apterous, or second form individual of the reproductive caste, also called a supplementary reproductive.

land and desert shrubs. We are not facing, therefore, any sudden invasion of new forms, as many have imagined, but simply an adjustment with species already present for millions of years before man entered upon the scene and began changing the conditions affecting the lives of termites. The possibility of future invasions is still a real one, however.

The biological factors of primary significance which should be understood in developing methods of prevention and control of termite damage, in so far as these methods are of a structural character rather than of a preservative or repellent nature, are (1) the swarming alates' mode of entrance into wood; (2) conditions under which extensions from old colonies occur; (3) the season, time of day, and weather conditions at periods of swarming; (4) the moisture requirements of each species; (5) the rate of growth of the colony and the ultimate size it attains; (6) the extent to which supplementary reproductives function in the extension of the colony; (7) the kinds of structures attacked with reference to ground connections, moisture, heat, elevation, and structural relations; and (8) the location of reservoir colonies in nature from which infestations spread to man-made structures.

The biological considerations which are concerned in the efficient inspection of structures for termite infestation are (1) the characteristic appearance of the burrows, covered runways, frass, or pellets, and typical locations of the species of termites occurring in the locality; (2) the distinguishing [illegible] of the different species, especially of the soldiers, alates, and [illegible] and supplementary reproductives; (3) the typical locations from which the swarming alates are wont to emerge; (4) the season of the year and time of day at which swarms occur; and (5) the changes in resonance of wood resulting from infestation.

The termite problem arises because of man's attempts to change the ordinary processes of nature by preserving for his own use over considerable periods of time, wood and its products, which it has been the immemorial function of the termites and associated organisms to break down and return to the soil and the atmosphere. The solution of the termite problem lies in man's interruption of the chain of events in the life cycle of the insect at some weak or accessible link, as by preventing or repelling the invasion of the primary pair of reproductives, or poisoning of the incipient colony.

Termites, like other insects, have six legs (fig. 27). At all stages after hatching, the body of the termite is made up of segments arranged in three regions: head, thorax, and abdomen. The head bears one pair of antennae, or feelers, and a pair of mandibles, or jaws, and other complicated mouth parts. In some cases a pair of black compound eyes is present (figs. 1*a*; 9*c*). The thorax is made up of three segments, each of which bears one pair of legs. The wings of the alate stage (fig. 1*a*–*b*) are borne on the last two segments of the thorax. (See chapters 5 and 6 for details of external and internal anatomy of termites.) Most of the individuals of any species of termites, however, are entirely wingless (fig. 71*a*), and are either entirely eyeless or possessed of but vestiges of eyes. They live habitually in the dark, and actively shun the light—that is, are cryptobiotic.

Termites fall into two major habit types (chap. 12), *wood-dwelling termites* and *earth-dwelling termites*. Wood-dwelling termites confine themselves to wood, the whole colony being contained in the wood, in many cases only in the individual piece which they are eating. Most wood-dwelling termites attack only dry, sound wood and are known as *dry-wood termites*. Others, known as *damp-wood termites,* are found in damp, and therefore usually decaying wood. The latter are largely confined to the Pacific Coast of the United States. *Earth-dwelling termites* are of several different types (p. 129), of which by far the most important from the economic point of view are the *subterranean termites.* They live in the earth and in wood in contact with the earth, and feed upon wood placed in or on the ground, and from such wood as a center extend their attacks to wood removed from ground contact. In some cases they build tubes or covered runways from their galleries in the ground (figs. 48, 49) over wood, plaster, or cement, to wood at higher levels, even to the second story of dwellings.

It will be seen that all types of termites live habitually in narrow galleries and passageways. These galleries may be entirely within the wood, as in the case of the wood-dwelling termites, or in burrows in the earth connected with galleries in the wood upon which they feed, as in the case of the earth-dwelling termites. Termites are all thus protected from many of the accidents, exposures, and contacts characteristic of the life of most insects. Each colony is an isolated unit, not easily located, and usually reached with difficulty. Its members are shut off from attacks by other animals, and even from contact with other colonies of the same species. Termites are thus able to live securely by the side of their deadliest enemies, the ants.

These habits of life render impracticable the methods used for the control of other insects, such as biological control by the use of enemies, the use of poison bait, as in the control of common house ants, the use of traps, or the widespread distribution of contact or food poisons, as in the spraying of fruit trees for the codling moth, the poisoning of mosquito breeding grounds, or the dusting of cotton fields by aeroplanes for boll weevil, or the use of poison gas for grasshoppers. On the other hand, the concentration of the colony and the grooming habits of its constituent individuals facilitate the distribution and eating of poison dusts by its members.

Termites are thus not ordinarily visible to man except at the swarming period. Their secretive instinct limits their life at all other times to their burrows in the earth, or in natural vegetation, or in wood products. Their burrows in the earth are small, not easily disclosed, pass undetected, and can only be found by diligent inspection and great care. Their burrows in wood come to notice only when the dead parts of trees, and the logs, poles, timbers, or houses in which they live are opened for inspection. Their devastations in the wood in which they are burrowing are often preceded by fungus attack and followed by the resulting dry rot and decay, which obscure or wipe out the damage which the termites themselves had previously accomplished, though this is less evident in the case of the dry-wood termites. Termite damage, except in its final stages, may therefore escape detection, and after its completion be attributed to other causes to a misleading extent.

The food of termites is primarily cellulose invaded by fungi, and is usually obtained from the wood within which their burrows are made. A pair of hard, horny jaws with saw-toothed edges which work against one another (fig. 6*a–c*) make it possible for the soft, weak-looking termite workers to shave off tiny fragments of the wood. The enlarged lower intestine of a termite (fig. 15 *(1), (2)*), examined under the microscope, will be found to contain these wood fragments in great numbers. Except in the family Termitidae, this wood can be utilized only by the aid of other organisms, which distend the intestine in a swarming, seething mass of minute animals of several kinds belonging to the flagellate Protozoa (chap. 7), each consisting of a single cell. Associated with them are numerous bacteria and spirochaetes of various kinds. The bodies of these tiny protozoans are crowded with the wood fragments, whose digestion here is a necessary step in the ultimate utilization of wood in the economy of termites.

Earth-dwelling termites (chaps. 13–18) destroy wood, not by attacking it directly from the outside as most insects attack vegetation, but rather by entering it from the ground or from another piece of wood in contact with the ground, and then feeding within the cavity thus made, but always retaining intact the outer protective shell of undamaged wood. The wood-dwelling termites, however, enter the wood directly from the air, through cracks, checks, or otherwise, but after the entry of the original primary pair the colony which develops from them also works entirely within the wood, except for the occasional discharge of fecal pellets to the exterior through minute holes opened for the purpose and promptly closed.

Wood is the most resistant and durable product of vegetation. Leaves and fruits are readily utilized by the insect world generally, but wood is exempt from general insect attack, is physically resistant to their feeble eating mechanisms, and chemically unsuitable for their prevalent modes of digestion. Among insects, termites and the wood-boring beetles accomplish a unique function in the scheme of nature by their assistance in returning this resistant wood to the air and soil, from whose chemical constituents it took its origin. Termites thus occupy a unique place in the natural cycles of water and carbon dioxide, since they contribute to the breaking down of cellulose, especially in the tropics. The proteins, sugars, starches, and oils produced by plants are subject to easy disintegration, whereas cellulose, by reason of its physical and chemical powers of resistance, is less subject to bacterial action and to digestion, and is capable of a persistence in nature not exhibited by the other products of photosynthesis. Thus it comes about that cellulose, which is so large an element among the products of phanerogamic growth, is the basis of the evolution of termites. Their utilization of it with the aid of fungi brings them into competition with man, and increasingly so as human culture advances.

Associated with the termites in this biological scheme of returning to the air and soil the constituents of cellulose are the fungi (chap. 9) which grow in wood, and some of which are responsible for its decay. The conditions favorable for termites are also favorable for fungi, and hence these two organisms are very commonly found in close and lasting association. The galleries of termites are kept closed, so that the air contained therein is humid up to the point of saturation from the moisture of the respiration of the colony and from the wood itself. Certain tropical termites cultivate a fungus in their nests and feed their young upon it. Miss Hendee (chap. 9) has shown that the galleries of even the dry-wood termites always contain an extensive flora of fungi, even immediately below the fresh surface of the new galleries. Subterranean termites and damp-wood termites of California are closely associated with fungi in soil and decaying wood (Hendee, 1933). There is evidence that the film of wood which termites eat in the immediate surface of termite galleries contains the hyphae of molds and other fungi and that termites carry the spores with them as their burrows are enlarged and also when they emerge from colonies and seek new locations at swarming time. Spores and hyphae occur on their bodies, and cultures from their exterior, their digestive tract, and their pellets almost universally yield fungi.

Bacteria live in abundance in the digestive tract of the termites and may possibly share in the chemical processes by means of which cellulose is broken down into sugar. The source of the proteins in the food of termites still remains problematical. The amount of protein in the heartwood of trees is very small. Whether nitrogen fixation by bacteria or other micro-organisms occurs in the gut of the termites, in wood prior to ingestion, or in their pellets, which are habitually eaten, remains as yet unsolved. Beckwith and Rose (1929) have shown that a cellulose-fermenting bacillus can be isolated from the gut contents of several genera of American termites. We sometimes find associated with both the subterranean termite (*Reticulitermes*) and the damp-wood termite (*Zootermopsis*) the wood-destroying fungi, which may work with these social insects to the ultimate destruction of the wood they occupy; but no specific relations between particular fungi and termites have been found. The fungi may be of value to termites in the preliminary softening of the wood, particularly during the incipient stages of the development of the colony, but their most important function is probably the fulfillment of the protein and vitamin requirements of the termites (Cook, 1933).

Termites may thus be contributing agents in the maintenance and distribution of wood-destroying fungi, though these fungi are not in any known respect dependent upon termites for their existence. The termites accomplish this by providing shelter and humid atmosphere favorable for the growth of fungi, by carrying the spores of fungi on their bodies, in their digestive tracts, and in their pellets, into their most advanced burrows in the sound wood. The activity of the fungi persists long after the extinction of the termite colonies. It may happen that a wood-destroying fungus is assumed to be the sole agent responsible for the destruction of wood, whereas extensive or prior inspection would have revealed burrows and frass indicating that termites had been active agents at one time in causing the damage. An intelligent estimate of the relative importance of fungi and termites in the destruction of wood is difficult, if not impossible, because of the fact that the destructive action of termites is more evident in the early stages of the process, whereas the action of fungi persists throughout the process and is evident long after the termites have disappeared, especially in the case of subterranean termites. This relation may lead to an over-estimate of the part played by the wood-destroying fungi and an under-estimate of the part played by termites.

Primarily, termites avail themselves of cellulose only after the death of the plant. They therefore occur predominantly in stumps, stubs, fallen logs, dead branches, and in exposed and hidden roots. Even annual vegetation and the perennial plants of forest and desert are utilized by the subterranean termites. These extensive natural reservoirs are centers from which termites enter the commercial and industrial products which civilized man fabricates from wood and other forms of cellulose.

Man thus modifies the life of termites in another very important feature, namely, by providing for their distribution into new and hitherto unoccupied areas. This is brought about not only by the contiguity of wooden structures, but also by the transportation of infested soil and wood in the ordinary course of commerce. This is well illustrated in the detection of imported species of termites at Honolulu, noted elsewhere (chap. 27). Man has merely added to and enlarged the function which rivers and ocean currents have served in the history of the group. This is brought out by the distribution of the termites throughout the islands of the Pacific Ocean (Light, 1932*b*), the same species being present from the Hawaiian Islands to the Marquesas, one species, *Cryptotermes piceatus* (Snyder), being distributed from Midway Island through Hawaii and Fanning Island to the Marquesas. This same species was probably shipped from Honolulu to Chinese ports and back again, since it has recently been found in goods entering Honolulu from Hongkong (Snyder, *in litt.*).

In a smaller way, the transport of household furniture, second-hand infested timbers, living plants, etc., affords a mechanism whereby colonies of termites become established in newly developing centers of human population and in regions wholly new for the species. An example of the latter is seen in the arrival in Hawaii of the oriental termite, *Coptotermes formosanus,* from Asiatic ports, and its occupancy of, and permanent installation in, the island of Oahu, already occupied by at least three other native species.

Man's relation to the termite's cellulose cycle is an important one in that he makes available to the termite large concentrated stores of cellulose. He groups wood in buildings in cities and villages, and spaces it conveniently along his lines of transportation in pole lines and fence posts, often with exposed sapwood. These foster the local concentrations of infestation, facilitate the spread of termites from one locality to another, and assist in the extension of infestations from the already existing natural reservoirs of the different species. Man buries timbers in soil already inhabited by termites, which find in it their natural food supply in roots and stumps of forest and field. He places his houses, barns, and other structures in contact with the earth, thus favoring infestation by subterranean and damp-wood termites. He builds structures with convenient crevices in roofs and walls, into which dry-wood termites may find entrance and establish colonies. Man extensively provides conveniently grouped and comfortably heated homes for these wood-eating insects. The social organization of the human species thus supplements and favors the maintenance and spread of these social insects by providing, alike, food and shelter, grouped and distributed most favorably for the organized life of the termite.

In another particular man's activities favor the life of the termite in that the wood made available by him for this insect is not as a rule that dying on the stump and thus slowly brought to the verge of decay, but the tree killed in the full flush of its activity and rich in the stored products of photosynthesis. Such killed wood contains more proteins and other food elements desirable in the diet of termites than other dead wood (chap. 43). These products are variously distributed in the tree according to season of the year and other climatic factors, and are also differentially distributed in the several parts of the trunk. In general, sapwood contains a liberal proportion of these products, and is also more attractive to termites than the rest of the tree trunk because it has a smaller amount of the more resistant lignin than has the heartwood. This differential distribution in wood of small amounts of the other products of photosynthesis desirable in the diet of termites is undoubtedly one of the factors underlying the seemingly erratic incidence of termite attack and of the distribution of termite burrows in timbers. It may also be concerned in the differential susceptibility of wood to fungus attack, and thus indirectly be tributary to termite selection of, attack upon, and damage to wood.

Termites, like bees and ants, are social insects living in colonies (chap. 3). Like bees and ants they work together, performing special tasks for the good of the colony, but, unlike them, they live together continuously, instead of interruptedly, in the nests or burrows. This colonial habit has given rise to different kinds of individuals or castes (fig. 1) fitted structurally to perform definite functions in the life of the colony: soldiers for defense; a king and queen for reproduction, often replaced or supplemented by the supplemental reproductives; and usually a special caste called workers for the collection of food, the care of the king, queen, soldiers, and young, and for the construction of the nest, burrows, exits, tunnels, towers, and exploratory extensions of the burrows. The workers are aided in these labors by the immature stages of the other castes, known as nymphs. Indeed, in the simpler termite colonies there is no specialized worker caste, and the work of the colony is accomplished by the nymphs only.

One interesting difference to be noted between the colonies of termites and those of bees, wasps, and ants is that in termite colonies males and females are equally represented among reproductives, workers, and soldiers, while among some other social insects females predominate. In the early stage in the development of a colony of termites a single primary king and queen remain as the reproductive pair throughout the life of the colony or for a prolonged period. The presence of this primary pair in the colony seems to inhibit the development of the reproductive function in all of the offspring, both male and female, while resident in the colony. The alates become functional reproductives only after they leave the parent colony and, in isolation, start a new one. In some genera of termites, however, there may be more than a single reproductive pair, several kings and queens, not necessarily equal in number, living together amicably; in others a polygamous state is definitely normal.

Experimentally, and perhaps in nature, our common subterranean termite, *Reticulitermes hesperus* (chap. 14), can form "empire colonies" with several primary males and females, though usually such unions are the occasion for a fight to the finish, with one pair the victors.

When the primary reproductives are removed from the colony by death, or when nymphs are detached from the colony without king and queen, supplementary reproductives develop in the colony from the fifth and sixth instars, or nymphal stages; rarely from the last, or seventh, instar. These new males and females differ in structure from the primary pair, and also differ according to the instar from which they are developed. The supplementary pair or pairs take over the reproductive work of the colony. If only one pair is developed no others develop later in their presence. In exceptional cases, however, several kings and queens may develop at the same time in the detached colony.

This adaptation to colonial life has the advantage of specialization of its members, and releases the maximum numbers of individuals for the utilization of the food supply and work of the colony. It also theoretically insures the potential immortality of the colony so long as any small fraction of it can find shelter and food for seven weeks, the time required in *Reticulitermes hesperus* for an egg-laying queen to develop from a fifth instar. It also provides a mechanism for the extension of a parent colony around the whole periphery of its habitation into new areas reached by its exploratory tunnels.

The prevalent idea that a termite colony can be exterminated by finding the queen's cell and destroying her is true only in so far as it brings about a temporary cessation in the growth of the colony. In many species of termites the primary queen will in time be replaced by an equally fecund supplementary queen.

The majority of individuals in the colony are workers and nymphs which are blind and weak, and particularly helpless when exposed in the burrows. They cannot long survive the drying influence of heat and air currents, and die very quickly when removed from the dark, moist, crowded conditions of their dwellings. The swarming forms, however, are typical insects (fig. 1*a*) with large, black, compound eyes, long wings, and a hard, pigmented outer skeleton. These winged termites, or alates, are the matured males and females, the potential kings and queens of new colonies. On alighting after swarming they prepare again for the customary habit of life of the termites by rubbing off their wings and assorting themselves in pairs. These swarming termites are the prey of birds, lizards, ants, and even of man in certain parts of the world. Those which succeed in pairing and in escaping their enemies eat their way into wood or dig into the earth and start new colonies.

The colony develops slowly for the first year, but in many species the queen becomes gradually swollen (fig. 1*h*), due to the enlargement of the ovaries, increases rapidly in egg-laying powers, and the colony soon increases in numbers, to millions in the case of some tropical species, many thousands in the case of our subterranean species, and many hundreds in the case of wood-dwelling termites.

The termites as a group are fundamentally characterized by their social instincts. All of the fifteen hundred or more species thus far discovered are social in their habits. Their secretive mode of life removes them from contacts with other insects, even from termites of their own species other than those in their own colony of genetically related individuals. Their enemy reaction to other insects may be the result of the age-old battle between ants and termites. Ants prey eagerly on termites whenever they are available, at swarming time, or when colonies are torn open. The habit of termites of living in closed burrows is the mechanism by which they successfully ward off destruction by these, their hereditary enemies. The ants constitute an ever-present menace to the existence of the termites, but the evolution of the burrowing habit is the latters' successful answer to this menace.

The repugnance to other insects on the part of the termites does not, however, extend to certain peculiar insects, chiefly beetles and flies, which habitually live only within the colony of a given species of termite. Many of these in the course of evolution have taken on a superficial resemblance in bodily structure to that of the termites with which they are associated. Termites not only tolerate them, but, in the case of migrating species, they are accompanied by these termitophile associates much as civilized man is attended by his domesticated animals. However, in the case of the termites, there is in many instances no evidence whatever that they derive any benefit from this association. The advantage seems to be mainly on the side of the termitophile associate, although its exudates may be eagerly utilized by the host termites.

This social habit of life is accompanied by a number of very marked instincts which together serve to maintain the colony. Among these are the recognition of members of the colony by odor, and the antagonism to members of other colonies, which leads at once to the destruction of the stranger. The grooming habit, a natural response when two termites meet, not only serves to remove dust, molds, and offending particles from one another, but also yields the much desired exudates from gland cells. The cooperation of different individuals in the construction and operation of their burrows, the building of complicated nests, and the cultivation of fungus gardens therein, all call for the direction and coordination of effort in the removal of wood and in the selection and placement of materials used. Each species of termite has its own recognizably characteristic pattern of burrow or nest, often irregular and seemingly lawless, but still characteristic. Some tropical species build elaborate nests of unique design (figs. 25*a*, *c*; 32).

A characteristic feature of termite engineering is the retention of the protecting outer shell of the timber whose interior is being excavated. Termites seldom, if ever, pierce this except to permit the exit of alates or to remove pellets. All openings are promptly closed and breaches into the burrows walled off by new construction. Termite-invaded structures are rarely, if ever, so completely riddled as to fall of their own weight. Sufficient wood is left to maintain the structure intact unless wrecked by external agents, such as earthquake (chap. 56), storm, or the increase of burden carried, as occurred in one instance when a recently installed piano crashed through a termite-riddled floor and joists.

The exploratory instinct of termites is shown in the construction of runways over cement walls and tunnels through the earth for relatively very long distances, apparently in search of new sources of food supply or favorable exits for alates, directed by delicate responses to stimuli as yet very imperfectly understood. This may be exemplified in the selection of particular boards and timbers among the many available in an infested structure.

Another instinct which is basic in the social habit of these insects is their ceaseless industry. They have never been observed to rest for any considerable length of time except when chilled or when molting, and under normal conditions of moisture and temperature the workers or nymphs toil ceaselessly in the various industries of the colony.

Termites instinctively communicate with one another on contact in the burrow by means of their long, sensitive antennae, which play rapidly over the surface of their neighbors. Alarm is also communicated throughout the colony by stridulating movements of the soldiers, feebly imitated by other members of the colony. The hard heads of the alarmed soldiers are rattled against the resonant walls of the narrow burrows, producing sounds which may be heard by applying one's ear closely to the surface of an infested post or pole. Rapping the pole sharply with a hammer will call forth these sounds of alarm. At a dinner meeting of the Termite Investigations Committee in San Francisco the alarm signals of *Zootermopsis* in an infested log were broadcast in the dining room by a loud speaker by means of pick-up and amplifying devices (chap. 50).

Termites instinctively seek environmental conditions favorable to their existence. They exercise a selection of the pieces of wood in which they burrow extensively, passing through redwood directly to expand their burrows in Douglas fir, and leaving Douglas fir to enter cherry (p. 228). They also, when given the choice under experimental conditions, select the degree of humidity most favorable to them, the desert-dwelling forms tolerating a lower level than the termites accustomed to living in the saturated atmosphere of rotten wood.

The social life of the termite colony has brought about a more or less complete dependence of its highly specialized individuals, namely, the king and queen, the soldiers, and the first instar, upon the nymphs or workers for feeding. All of these specialized castes are more or less helpless and, if isolated, soon starve, because they are unable to feed themselves. The slow growth of the colony in the first year, when its care is for a time entirely dependent upon the primary king and queen, is probably due to their inability to feed effectively. Laboratory observations reveal fecal feeding. The extruded pellets are eagerly seized and devoured and fluid droplets from the rectum are even more quickly taken, even to the extent of draining the intestine of its fluid contents. This proctodeal method of feeding provides a method of transfer of the protozoan fauna which is essential in the digestion of the wood the termite has eaten. It is supplemented by stomodeal feeding by means of regurgitated fluid. The use of pellets as food also adds molds and fungi growing therein to the protein-poor diet of the termite.

The helpless soldiers, whose jaws are so modified for defense as to render them useless for gnawing wood, and the inefficient and otherwise occupied king and queen, are fed by one or both of these methods by the workers or nymphs. The young nymphs, upon hatching and until after the first molt, are apparently unable to feed upon hard wood. They can be seen perched in an expectant attitude in the colony, with their mouth parts at a level where regurgitated food or anal droplets can readily be received. The continuance and rate of growth of the termite colony is dependent upon the effectiveness of these instincts of the workers and nymphs for the care of the dependent castes, and, perhaps, also upon the intelligence acquired during the relatively prolonged life of the seven nymphal instars.

The keen sensitiveness of termites is remarkably provided for by an elaborate system of tactile sensory hairs on all projecting parts of the body, and by a diverse group of specialized sense organs on the antennae and mouth parts. The biting jaws of the termite are densely and exquisitely innervated (fig 6*e*). Stimulation by touch, odor, taste, and pressure guide the complicated reactions and instinctive behavior of the complicated social life of termites. Indeed, the coordinated behavior seems at times to attain the higher levels of action which may be designated as intelligent. The social life of the termites seems to have permitted the individual to benefit by experience, and to have raised the level of behavior in some of its aspects from instinct to intelligence.

As civilization advances human culture also avails itself of cellulose in ever increasing amounts and wider uses. Man thus increasingly meets the competition of these hidden and widespread utilizers of cellulose. The organized social life of man and the organized social life of termites mutually interact in continuously enlarging the field for the activities of the latter. The two organizations unite to provide new and more rapid modes of distribution and transportation of both immature and winged termites to new sites of infestation, and to accumulate and utilize in more available form the primary food supply of these destroyers of wood.

Termites, fungi, and fire have tended, often unnecessarily, to divert man from wood to adobe, clay products, and stone for his buildings. The cost of the conquest of the tropics by modern civilization is increased materially by the termite menace.

The results of our investigations should be reassuring alike to the producers and consumers of wood. Structural methods are here made available to the builder, architect, and engineer, which if used and supplemented by inspection and maintenance, will greatly reduce and even ultimately render insignificant the loss due to termite attack (chaps. 46–56). In addition, by relatively inexpensive chemical treatment, the maximum use-life of lumber and of wood products can be obtained, and wood insured even in the tropics against termite attack. The home owner can definitely rid his house of termite infestation by simple and effective methods. The conservation of our forest resources and the wider and continued utilization of forest products will both be enhanced by a policy of continuous warfare against termites.

CHAPTER 2

CLIMATIC FACTORS AFFECTING THE LOCAL OCCURRENCE OF TERMITES AND THEIR GEOGRAPHICAL DISTRIBUTION

BY

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The local occurrence of termite colonies is restricted or favored, and thus determined, by the effect of certain physical factors which are customarily specified as climatic. The most important of these are atmospheric and soil moisture, which results in the humidity enveloping the termite, and temperature, which determines the relative humidity and accelerates, restricts, or wholly inhibits vital processes according to its changing level and to the directions of its changes.

Since termites in their prolonged larval stages have only a thin and relatively delicate outer covering, they are exceptionally liable, as compared with other insects, to loss of water from the body by evaporation. This liability is compensated for by their habit of living in closed burrows within which they habitually maintain by control of the openings an atmosphere approximately saturated. Before they leave this protected environment for the brief flight at the swarming season the covering of the body is changed to a darker color and harder consistency resembling that of insects habitually exposed to the dessicating effects of the open air.

Termites secure their water in part from that physically incorporated in the soil or in the wood surrounding their burrows, and in part from the products of metabolism. In the burrows of the subterranean termites humidity is maintained in part by the diffusion of moisture from the soil water through their ground connections. The rate of such diffusion operates to set the upper limit to which their workings may be extended in a building, pole, or post.

The damp-wood termite is particularly dependent upon abundant moisture, such as that retained in rotting logs, in the staves of water tanks and pipe lines, in bridge piling, in dead knots in living wood, in harbor structures near and over the sea where continuously high humidity is prevalent, and even in water tanks on high buildings in San Francisco.

The subterranean termites *(Reticulitermes)* find in sandy soil much more favorable conditions than in the heavier, less porous, clayey adobe soils. They are especially given to finding and attacking wood buried in the soil, and to following out the dead roots of trees and plants under natural conditions in gardens and forests.

I. FIELD OBSERVATIONS ON THE RELATIONS OF MOISTURE TO THE DISTRIBUTION OF TERMITES IN NATURE

The study under laboratory conditions of the preferences of termites for a humid atmosphere, and the revelation of their sensitiveness to minute differences in humidity, throw light upon many questions of geographical distribution of species, on variations in habitat of the same species in different localities, and on changes in location at different seasons of the year and even at different times of the day. A knowledge of this dependence of the termite colony on moisture is useful in interpreting, in part, their patterns of burrowing; their seeming preferences among different woods and different pieces of the same wood; their locations in posts, poles, and parts of buildings; and their seasonal and diurnal movements within their residential limits. It is obvious that moisture is also essential for the growth of fungi, which play an essential part in the diet of termites.

Termites are peculiarly dependent upon moisture, although their diet is sometimes seemingly dry wood, and a regular water supply in the usual meaning of the term is not provided in their environment. All members of the colony except the king, queen, and recently alated reproductives about to leave the colony, lack the dry, dark, hard, chitinous protective covering of the body which checks evaporation. Their outer covering is soft, white, and inadequate to protect the body from drying up quickly. The fluid of the termite's body and greatly distended digestive tract comes mainly from the conversion of wood in metabolism, supplemented by the residual water left in the wood even after it is kiln-dried. This is estimated to be from 6 per cent to 20 per cent. Dead limbs of trees, through their ducts, still derive some moisture from their connections with living parts of the tree. Hence, colonies of *Zootermopsis angusticollis*, which ordinarily frequent moist, rotten wood, can live in dead knots or beneath scars left on trimming off limbs, because their burrows are carried into the margins of the sap-filled living wood. This connection enables them to maintain a saturated atmosphere in burrows entirely detached from moist earth and at a considerable elevation above the soil.

Timbers in contact with the earth, such as posts, piles, bridge piling, bulkheads, railroad ties, mudsills, and other parts of buildings placed in contact with the earth or damp masonry, exert a lamp-wick capillary action, especially in vertical timbers with undisturbed sapwood. Stumps and roots, though dead, have a comparable moisture-raising function. This lamp-wick action favors termite infestation, and the variations in its operation affect the distribution of termite invasion. Thus the extent of the attacks of the subterranean termite on posts and poles is to a considerable degree governed by the elevation of moisture derived from the soil in the lower part of the pole. In general, in the main area of their greatest frequency in the coastal regions of California and in the less arid parts of the central valley, attack by the subterranean termites on posts and poles is mainly in the interred butt and upwards in the pole for a few inches to several feet above the ground line. In the more arid regions the elevation of attack decreases, and in the desert itself infestation is largely limited to wood in the soil. If the butts are encased in cement, ideal conditions for the conservation of moisture are created and termite invasion is fostered. Several poles in Berkeley so treated were attacked to the top, a distance of thirty feet. At higher altitudes in the Sierras, as, for example, at Blairsden, California, at 4,414 feet elevation, where soil moisture is more abundant and less depleted in summer, and where some summer showers occur, attacks by *Reticulitermes hesperus* reach to the top of telegraph poles.

Access of moisture to wood used in buildings favors attack by the subterranean termite. Hence, termite attack is favored in untreated lumber in mudsills; foundation posts; footings; forms for concrete left in the ground; porches in contact with earth, cement, or brickwork near the ground; woodwork in basements, laundries, kitchens, ships' galleys, and near leaking plumbing or steam pipes; and the ends of joists in porous brick walls subject to access of moisture from the outside.

Sometimes the damp-wood termite is also attracted to wood thus favored with moisture, particularly if exposed. One interesting case was in the exposed flooring of the San Francisco Ferry Building. Here the large spikes had made small depressions which caught moisture, with resultant decay of small areas of wood about them, and in many cases colonies of the damp-wood termite were found taking advantage of the constant moisture supply. A similar attack was made by this termite upon heavy planking under an asphalted floor in a marine terminal building on the Oakland waterfront.

As Williams' tests (chap. 4) show, only a small amount of soil moisture, and presumably of wood moisture, is necessary to make possible a saturated atmosphere in the burrows if the air is confined. The termites take advantage of this fact in the management of their burrows. They seal themselves in when the colony is founded, using such reserves of body fluids for mixing their cementing material as they can command; they promptly close up openings made for the exit of alates or the extrusion of pellets; and they construct from wood frass, fecal pellets, and salivary fluid resistant dams within their burrows which wall off the older sections and thus cut down the volume of air to limits within which the moisture optimum is retained.

The first work which an isolated colony of 25 to 100 dry-wood termites undertakes in an observation block with a ⅜-inch canal and a longitudinal tangential glass window, is to seal up the entire margin where glass and wood are in contact and open up one or more direct burrows to the outside. This may be completed within twenty-four hours, but only if there is an abundance of moisture supplied. Without sufficient moisture the time required is greater, as their reserves are quickly exhausted. If test blocks are kept with a saturated atmosphere around them the termites open up their burrows more freely, and some may leave the block and wander about for a time; but they return quickly when light is admitted.

The ability to create and maintain a high humidity in their burrows with the aid of the moisture of metabolism, of the wood, and of the soil, enables dry-wood termites to invade dry wood independently of ground connections, and to live in semi-arid and even in desert regions. They are able to live and to thrive there in so far as they can find or create and control sufficient moisture in their burrows. Thus, also, the species of *Amitermes* which build earthen galleries over the surfaces of posts and poles in the desert, or completely ensheath small dead desert plants with earthen tubes, actually live in a saturated atmosphere. In the early morning they will be found in the upper ends of their galleries, at which time Williams found by dewpoint determinations that the atmosphere at that level of their galleries was saturated. During the middle of the hot, dry, summer day, however, the termites are not present in this part of their dwelling and the relative humidity therein is found to be much reduced. There is no doubt that in the lower portions of their galleries they are still in a saturated atmosphere, for Williams has found that even in the desert there is sufficient soil moisture (1 per cent in sand) to keep the atmosphere of cavities in a saturated condition within a foot or two of the surface.

In certain marginal zones Professor Light has observed that where the barren-lands termite, *R. tibialis,* and the true desert dwelling termites of the genus *Amitermes* occupy the same territory, a very interesting seasonal change in the surface fauna is to be noted. The area in question is in the lower reaches of San Gorgonio Pass, which leads into the northern end of the Colorado Desert of southeastern California. This area was first studied in late December after the autumn rains. *R. tibialis* was very abundant in wood on or near the surface of the ground. Workings of *Amitermes* were also found, but no *Amitermes* were taken. The area was next studied in the early autumn before the rains. At this time *R. tibialis* was very seldom encountered, but several species of *Amitermes* were very common. With the first cold rain the observable fauna changed overnight; *R. tibialis* was once more abundant at the surface, where there was now abundant moisture, and *Amitermes* had retreated to lower levels, probably because of its inability to withstand the lower temperature.

II. THE RELATION OF TEMPERATURE TO THE LOCAL OCCURRENCE OF COLONIES AND TO THE GEOGRAPHICAL DISTRIBUTION OF SPECIES OF TERMITES

Moisture and temperature are inseparable as environmental factors of termites. These insects respond quickly to temperature changes. Their individual behavior, which results in modifications of their seasonal, local, and diurnal distribution, is largely influenced by the temperature factor.

Colonies of subterranean termites in buildings will often extend and develop their burrows about furnace rooms, near steam pipes, and where warmth is habitually found. Exit openings for alates are made on sun-lit surfaces, and exit towers and tunnels are placed on warmed surfaces, or towards sources of warmth. *Kalotermes minor* in the northern part of its range is especially prone to infest rafters and roof sheeting, and southern frontages of dwellings. In Honolulu *Coptotermes formosanus* thrives in woodwork about superheated attics.

In desert regions, where the extremes of midday heat and the chill of night alternate, termites develop their burrows so as to shift their location to avoid exposure to the extremes. Differences in abundance of burrows sometimes seen between the north and south sides of poles may be correlated with the differential exposure to the sun's heat. The chill of winter slows down or suspends the activities of termites. It may also give direction to their burrows and shift their location within them. Thus, for example, *Paraneotermes simplicicornis* in poles in the delta of the Colorado River extends its burrows from slightly above ground level to the bottom of the pole. In cold weather in February all parts of the burrows are vacated except those at the very bottom of the pole, where the entire colony is segregated.

The geographical distribution of genera and species is determined by minimum and maximum limits of temperature. Thus, on the Pacific Coast *Zootermopsis angusticollis*, the damp-wood termite, extends as far north as Vancouver, as high as 9,000 feet in the Sierras, and thus to certain undetermined lower limits of temperature near the freezing point in winter, and south into the mountains of Lower California, where certain higher temperatures limit its southward extension. The genus *Reticulitermes* is the only one having a world-wide extension into temperate climates having severe winters.

The geographical distribution of the dry-wood termite, *Kalotermes minor*, in the northern part of its range shows relations to temperature. It occurs in isolated localities in the San Francisco Bay district, in Marin County, California, and even as far north as Fort Bragg, California, in warm and sheltered regions. On the other hand, as it enters heated desert regions, *Kalotermes* descends into the lower part of poles, even below the surface of the ground. The large cavities hollowed out by this species in the interior of poles appear to be retreats from the superheated surface.

The two factors, moisture and temperature, may act differentially on different species in the same locality at the same time. In California, on the margins of the desert, the two genera *Heterotermes* and *Reticulitermes* overlap, but neither progresses far into the territory of the other. The advance of *Heterotermes* is checked by the lower temperature of the coastal belt, and that of *Reticulitermes* by the lower humidity of the desert.

Both high temperature and high humidity are essential for the swarming of *Reticulitermes*. This occurs only on sunny days on sunlit surfaces of wood or the earth, beginning in the late forenoon after a recent rain and continuing until about four o'clock in the afternoon. On the other hand, *Kalotermes minor* swarms most abundantly on days following a sudden rise in temperature, often at low humidity and without antecedent rain. These two termites swarm during the part of the day with the most brilliant illumination. In contrast to these, both species of *Zootermopsis* swarm, even in the same locality, in the late afternoon and evening at a time of falling temperature and rising humidity. In the tropics generally many termites swarm at night only, when the humidity is slightly increased and when the light is dim. The swarming alates even of these night-flying species are attracted to the light, as are the day-flying species. This positive tropism to the light is reversed after the alates are paired as primary reproductives, and they become markedly negative, seeking dark crevices and digging into the earth or wood. They retain their negative tropism and shun the light for the remainder of their lives.

The relations of temperatures to the existing distribution of termites throws some light on the possibilities of the survival and spread of introduced species into new territories. With the growth of commerce, instances of the introduction of foreign species (chap. 27) tend to increase and their rapid spread may follow, as illustrated by that of *Coptotermes formosanus* following its introduction into Honolulu.

The question as to the survival of this destructive species, if it should be introduced on the Pacific Coast, is a very important one. The fact that it infests wharf structures, enters packing cases, and establishes itself in the woodwork of steamships, favors its transit from Honolulu to other ports, especially on the Pacific Coast. The swarming of this destructive termite occurs at night, and the alates are attracted by light. In one instance they entered a lighted steamer at the dock, the doors and windows of which had been tightly closed to exclude them, through a pipe several feet in length and of small diameter.

The destructive activity of *Coptotermes formosanus* (chap. 27) in Honolulu has been so great as to cause concern about its introduction into ports on the Pacific Coast. The vigilance of the Federal Inspectors has intercepted it thus far, with the very active cooperation of American steamship companies operating between the Hawaiian Islands and Pacific ports. The menace of the importation, however, will continue to exist, and not only the Federal authorities and shipping interests should concern themselves about the matter, but every instance of an unusual termite infestation coming to the attention of any householder, contractor, or biologist should be reported at once to the Department of Entomology, University of California, and specimens of workers and soldiers should be sent in at once either in alcohol or in air-tight containers with moist paper.

The structures at and near localities where foreign ships lie at dock or at anchor, and buildings in which oriental and Hawaiian merchandise is received or stored, should be subject to regular inspection, and all infestations by termites in any goods, containers, or buildings in such localities should receive expert attention.

Some indication of the possibility of the establishment of *Coptotermes formosanus* on the Pacific Coast can be inferred from its present geographical distribution, and especially from the temperature limits in its present area of occurrence. This termite is essentially a subtropical species with northward extensions into the warmer parts of the temperate regions. It occurs in regions of considerable summer rainfall.

The temperature factor operates to limit the distribution of plants and animals at the two extremes of the winter minimum and summer maximum. The winter minimum kills organisms not adapted to such temperatures; the summer maximum is less wont to kill, but affects the reproductive cycle.

Breeding may be wholly inhibited above a certain normal summer temperature, but, if time permits, it may be completed in the spring or fall, though suspended in summer. On the other hand, some species breed only above a certain minimum temperature continued for at least a certain minimum time. It is also true that the sum of the season's advancing temperatures sets the dates at which given plants bloom and fruit, and at which many animals, notably insects, breed and produce their young.

The sheltered life of termites and their association with the more or less controlled temperatures in man-built structures both tend to obliterate or reduce the operation of the limiting function of the temperature factor in the occurrence of colonies and the geographical distribution of species. It has been observed, however, that even under laboratory conditions native California species breed more actively in the warmer months. It is therefore certain that *Coptotermes* will tend to survive and multiply wherever the winter temperature is not low enough to winter-kill it, and at the same time the summer temperatures are high enough and sufficiently prolonged above a certain minimum for reproduction. Conditions meeting these requirements will undoubtedly be found in heated buildings.

Another factor limiting *Coptotermes* is its habit of building a carton nest, in which the king and queen are found, in the ground. Only in exceptional cases in which there is sufficient moisture maintained in the structure is the carton nest found within a building. The limiting action of the winter minimum will therefore operate on nests in the ground to restrict the northward extension of *Coptotermes*. The moisture requirements of *Coptotermes* in the soil will be satisfied on the Pacific Coast in almost any locality with the existing moisture content. Irrigation of lawns and gardens will also foster its occurrence in communities.

Coptotermes formosanus was introduced into Honolulu, presumably by transhipment in soil of potted plants or in wood, from an Asiatic port. It might have come from Canton, Hongkong, or Shanghai, China; or Nagasaki, Japan. Its known geographical range, according to Light (1929*c*), is from the island of Hainan and from Canton on the south, to Shanghai on the north, in China. It also occurs in southern Japan on the islands of Kyushu and Shikoku, and at least as far north in Hondo as Idzu Province, not far from Tokyo. Okada (1912) reports it at Maisaka and Sodeshi in Shizuoka Prefecture at 35° 03′ N.

A comparison of the temperatures of winter and summer at the northern limits of the distribution of this termite in Asia with corresponding records on the Pacific Coast will serve to indicate at least in a general way the northernmost limits of the regions on the western continent presumably open to invasion and infestation by this destructive species of *Coptotermes*. Its success in the tropical climate of Honolulu is suggestive of the possibilities of a wide extension in the American tropics.

Data kindly supplied by Professor C. O. Sauer, of the Department of Geography of the University of California, enable us to compare the winter and summer temperatures at Kobe, Japan, near the northernmost limit of

Coptotermes in Asia, with those of the Pacific Coast. The mean minimum temperatures, that is, the monthly average lowest daily temperatures, at Kobe for December, January, and February for 1897–1926 are 37.58° F., 32° F., and 31.82° F., respectively. The locality in the United States which conforms most closely to these temperatures is Tacoma, Washington, where the winter minima are almost identical with those of Kobe, except that the lowest temperatures are reached in January instead of February. In so far as the winter minimum is concerned, *Coptotermes* may be expected to survive on the Pacific Coast as far north as Tacoma.

The relations of the accumulated summer temperatures to the breeding potentialities of any termite are not known as yet. Comparisons of the two sides of the Pacific on this basis are therefore not feasible. We have available, however, the mean maximum and the mean temperatures for Kobe for the period 1897–1926 for the summer months. They are included with comparable figures for Tacoma, Washington, and for San Francisco, Sacramento, and San Diego, California, in Table 1.

TABLE I

SUMMER TEMPERATURE ON ASIATIC AND AMERICAN COASTS WITH REFERENCE TO THE CLIMATIC LIMITS OF *Coptotermes formosanus*

Locality	June		July		August		*Mean for the 3 months*	
	Mean maximum temperature	Mean temperature	Mean maximum temperature	Mean temperature	Mean maximum temperature	Mean temperature	Mean maximum temperature	Mean temperature
Tacoma	67.6° F.	58.9° F.	73.2° F.	63.3° F.	72.7° F.	63.0° F.	71.2° F.	61.7° F.
San Francisco, 1871-1932	65.5	58.7	65.0	58.8	65.2	59.3	65.2	58.9
Sacramento, 1881-1932	83.4	69.4	89.4	73.2	88.6	72.9	87.1	71.8
San Diego, 1875-1932	69.3	64.1	72.5	67.5	74.0	68.9	71.9	66.8
Kobe, Japan, 1897-1926	78.4	70.3	85.6	77.5	80.2	80.4	84.4	76.1

The table shows that the mean summer temperatures in the months of June, July, and August at Tacoma and San Francisco, 61.7° and 58.9°, respectively, are considerably lower than at Kobe. The difference is sufficient at least to slow down the rate of growth of colonies of *Coptotermes*. Whether or not it would completely inhibit their reproduction is not at present known.

The mean summer temperature in the central valley of California, for which that of Sacramento is fairly representative, namely, 71.8°F., is very close to that of Kobe, namely, 76.1°F. This indicates that *Coptotermes* could multiply successfully in this valley and in other warmer parts of California away from the cooler regions immediately along the coast, if not in many of them also, as, for example, in San Diego, where the mean summer temperature is 9.3 degrees below that of Kobe.

The extensive field observations of the Termite Investigations Committee have not brought to light any infestation in California by *Coptotermes formosanus*. Another Hawaiian termite, *Cryptotermes piceatus* (chap. 27), arrived at a California port in household furniture which had been in storage in Honolulu, but was detected and exterminated. The extensive inspections of wooden structures throughout California by the field biologists of the Termite Investigations Committee and by termite operators in the larger cities of the state have brought to light evidence of widespread infestation by *Reticulitermes hesperus* and *Kalotermes minor*, and more restricted infestations by *Zootermopsis angusticollis* and *Z. nevadensis* (chaps. 13–26). These are all native species of wide occurrence in the forests of California. No critical evidence of the invasion of any species from the arid Southwest into other parts of California has come to light.

On the other hand, the growth of communities and the rapid extension of cities, and the extensive use of wood in agriculture, in fencing, by the public utilities, and along the highways, provide ideal conditions for the invasion and settlement of naturally distributed termites from the forests, chaparral, and even from the scanty vegetation of arid districts. There is abundant evidence that the termites are not slow in availing themselves of this increase in food supply. This increase in colonization brings into play to some unknown degree the principle of geometrical progression which constantly tends to speed up the rates of infestation and to bring to light constantly increasing evidences of destructive termites. Strictly speaking, this increase is not due to new invasions, but only to the utilization of new resources of wood provided by man in regions previously infested or in those readily accessible from such regions.

CHAPTER 3

THE CONSTITUTION AND DEVELOPMENT OF THE TERMITE COLONY

BY

S. F. LIGHT

SIGNIFICANCE OF SOCIAL ORGANIZATION

Termites are preeminently social creatures and are to be understood only when so considered. There are solitary bees and wasps, but no solitary termites. Each of the fifteen hundred or more species known is definitely colonial. This long-seated habit constitutes both their strength and weakness. A knowledge of their social organization, therefore, is essential to any understanding of their capabilities and limitations in nature, as also of their persistence as a group and the dominant position which they hold in the faunas of certain tropical regions. Aside from their social organization they are simple, primitively organized insects with but few special structural adaptations, to enable them to hold their important place in nature. In fact, largely as a result of their social habits and the effective protection afforded by enclosed passageways and chambers, termites have in the course of their evolution become peculiarly lacking in individual protection against either predators or the adverse physical features of their environment.

FOOD SUPPLY

The development of a society is possible only if the individuals thereof are long-lived. This, again, is possible only when there is available a continuous food supply, and is favored by a uniform food supply. Most insects are adapted to seasonal food supplies. The young must depend on food of a kind different from that used by the adults or available only at a different season. Hence the generations do not overlap, as must be the case if there is to be a society. The termites are what they are today largely because they acquired at some unknown ancient period the ability to use wood-cellulose as food. Cellulose makes up most of the woody parts of plants and is constantly produced in great quantities by them. It is a carbohydrate, rich in energy. However, it is of peculiarly resistant chemical nature, and, with very few exceptions, animals are unable to digest it and hence cannot use it for food. Just how termites are enabled to do this remains as yet a partially unsolved problem. Their ability to do so has given them an abundant, continuous food supply and one for which they have few competitors.

CRYPTOBIOTIC HABIT

Associated with the wood-eating habit of the termites is their cryptobiotic mode of life. They live shut off from the light in enclosed passageways, either entirely in the wood on which they feed (fig. 33*a*), or partly within the wood and partly within the earth (fig. 33*b*). This mode of life, naturally arising from the burrowing habit, has had the extremely important effect of making them largely a group apart so far as enemies in the form of predators or parasites are concerned. They do not customarily encounter animals of other types or even individuals of their own species from other colonies. Indeed, they exhibit a highly developed antagonism to strangers from other colonies, and hence the possibility of spreading contagious diseases, so important in population control elsewhere in nature, is reduced to a negligible minimum among termites.

FACTORS INFLUENCING DESTRUCTIVENESS

The significance of all of these conditions in increasing the capacity of termites for continuous and extensive work, which in this case consists largely of destruction of wood, is obvious. Their individual longevity, the potential immortality of the colony (pp. 28, 41), the existence of a continuously available supply of energy-yielding food, their cooperative activity, the protection from enemies and physical vicissitudes, such as extremes of heat and cold, storms, etc., afforded by their cryptobiotic or hidden mode of life, all these result in the piling up of population and a consequently augmenting rate of destruction of wood by the colony.

CASTES

No significant and successful social regime is possible without division of labor and correlated specialization of structure and behavior. Division of labor, that is, distribution of different duties to different members of the colony, is extremely ancient among the termites and has been so important in the heredity of the various species of the group that individuals of different types, fitted by inherited structure and instincts to accomplish various important functions in the life of the colony, are produced and maintained in each colony. These structurally differentiated types within the colony are termed *castes*. With the exception of the single genus *Anoplotermes* (p. 134), all species of termites have in each colony at least the two distinct castes, *reproductives* and *soldiers* (fig. 1). In most species another fundamental caste, the *workers*, is also present (fig. 1). The species of the family Kalotermitidae (see chapter 10 for a discussion of the families of termites) have no special worker caste; here the immature stages of other castes perform the functions of the worker. In only the single genus *Anoplotermes*, mentioned above, is the soldier caste lacking, and here the function of defense devolves upon the workers.

Three types of reproductives occur, namely, primaries, secondaries, and tertiaries (pp. 266–269). These are considered by some to represent separate castes. The most complex colonies of California termites might therefore contain the following kinds of individuals: winged reproductives ready for swarming, three types of functioning reproductives, soldiers, and workers, as well as eggs, six or seven different immature growth stages of reproductives, and growth stages of soldiers and workers. In certain tropical genera of higher termites (family Termitidae) each colony contains soldiers of two or even three types which differ in size, and in some cases in structure as well (fig. 2). In some genera there are also workers of two or three types, differing chiefly in size. Thus, such a tropical species might have nine castes, three each

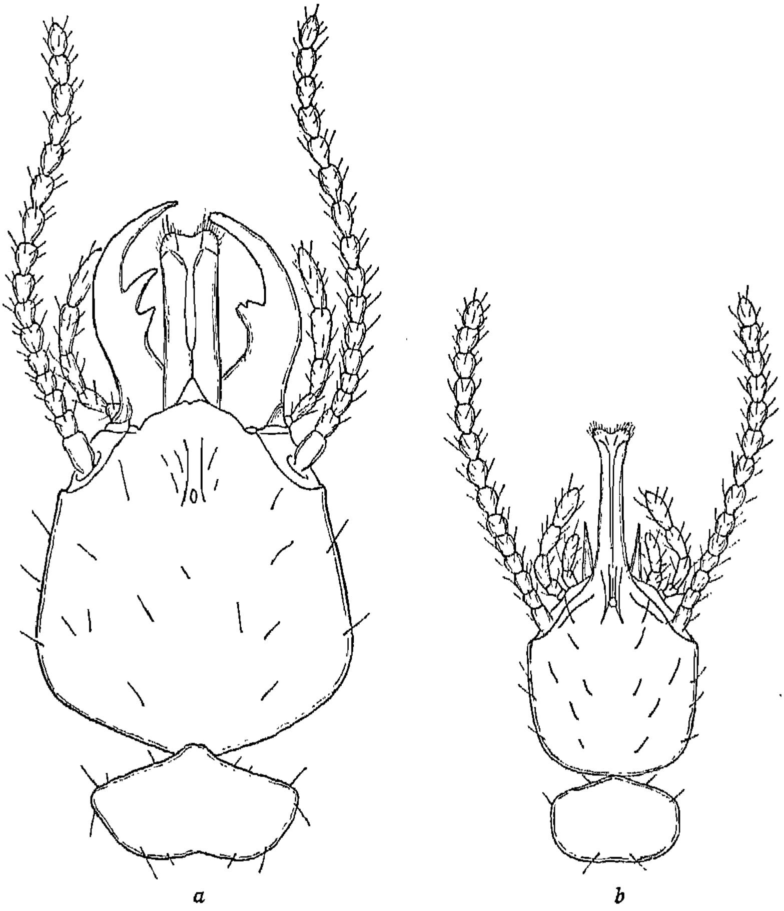

Fig. 2. Heads of the two types of soldier found in the colonies of a single species, *Rhinotermes latilabrum*, of the Amazon basin. Both types are specialized for chemical warfare. The upper lip (labrum) of each is drawn out into a long trough which directs the flow of a secretion which is toxic to ants. In the large soldier the mandibles are well developed, as is true of soldiers of most species, while in the small soldier the mandibles are vestigial. *Ca.* × 20. After Snyder (1926*c*).

of reproductives, soldiers, and workers. With these are found the winged reproductives and the various growth stages of each caste, making the colony and colony relations exceedingly complex.

INSTARS

The growth of an individual termite is discontinuous. Like other insects, termites are invested with an exoskeleton composed of chitin, which protects the soft internal organs of the animal. In order that growth may occur, this chitinous coat must be shed or molted at intervals (fig. 3). After the old coat has been shed, and before the new one immediately underneath has hardened, the animal expands sufficiently to allow for growth until the next molt. The stage or period between two such molts is known as an *instar,* and the individual usually undergoes four to ten, typically seven, such molts before reaching its final form as reproductive, soldier, or worker. An individual which has not reached its final form is spoken of as a nymph. The newly hatched nymph is in the first instar (fig. 1*c*), and the one just about to molt into an adult stage is said to be in the penultimate instar. The seventh instar is the penultimate instar of the winged reproductive of the damp-wood termite (fig. 3*a*). Figures 1*c, d, f* show, respectively, the first instar, the third instar, and the adult worker of the western subterranean termite, *Reticulitermes hesperus.*

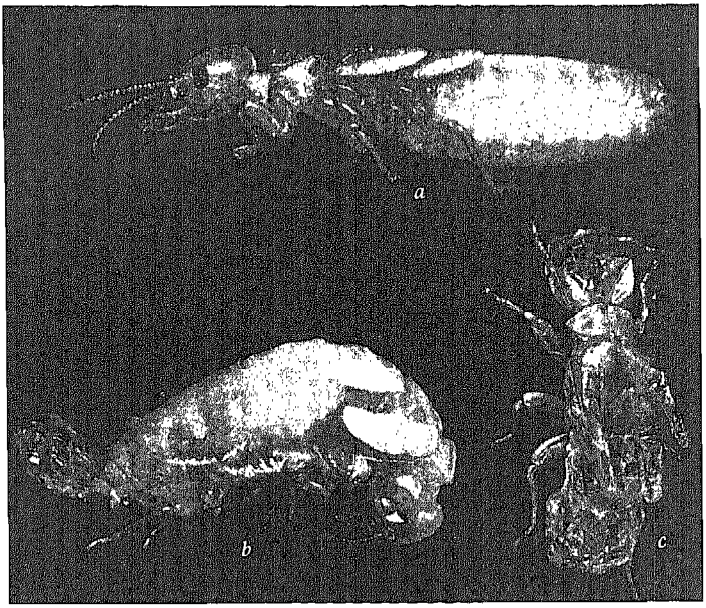

Fig. 3. Termite nymphs molt several times. The photograph above shows *b*, a reproductive nymph of *Zootermopsis* undergoing molt. It casts its entire outside skin, *c*, as well as part of the lining of the alimentary tract, and emerges in the last nymphal stage, *a*, with distinct, pigmented, compound eyes, and swollen wing pads, from which the adult wings will emerge at the last molt. From *Calif. Agr. Exp. Stn. Circ. 318, fig. 14.*

Constitution of a Developed Colony

Any mature colony of termites, therefore, consists of adult individuals of such castes as are characteristic of that particular species, typically *reproductives* (*king* and *queen* and *alates*), *soldiers* and *workers,* and, in addition, there are always present very numerous *nymphs* in the different *instars.* These nymphs are believed by some to belong to different castes, but these are not distinguishable from one another except in the oldest instars.

Upon opening the galleries of a termite colony, the great majority of individuals are seen to be pale, weak-looking animals, usually whitish in color, and somewhat grub-like in appearance. These are the nymphs of the various instars, together with the workers, if the species under observation possesses a worker caste. These individuals are all totally blind, except in a very few species. Their chitinous coat is thin compared to that of most insects, and there are no visible organs of offense and defense. As a group these nymphs and workers present a strikingly helpless and ineffective appearance; yet these very individuals, by virtue of their numbers and concerted activity, accomplish the destruction of wood and the construction of nests, mounds, and runways characteristic of the various types of termites. Some of these mounds are the largest structures in nature built by animals (fig. 25*a*).

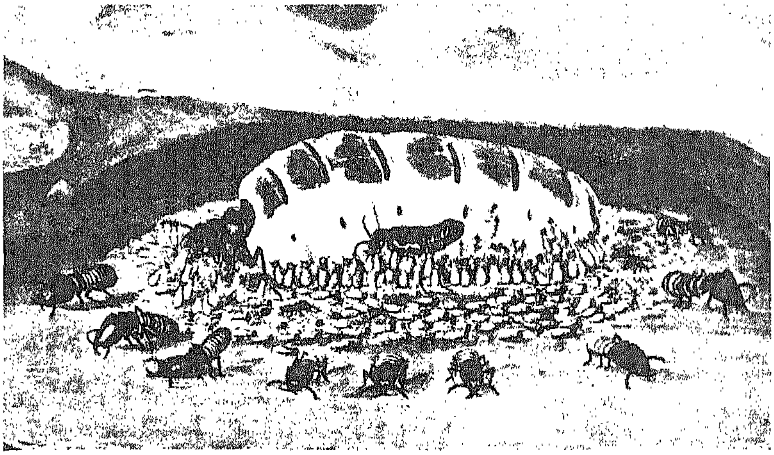

Fig. 4. Photograph of a drawing prepared for the purpose of illustrating diagrammatically the royal cell of a physogastric queen of *Macrotermes bellicosus,* a termite found in tropical Africa. From Escherich, *Die Termiten oder weissen Ameisen* (frontispiece). It illustrates the distended physogastric queen, the small king, the encircling workers grooming and feeding the queen, and a peripheral line of soldiers on guard. The conditions of termite life here illustrated are not typical of termites of the temperate zone.

Scattered among the nymphs and workers there is usually found a much smaller number of soldiers. A soldier is distinguished by its greatly enlarged, elongated head (fig. 89*d*), armored with very heavy, often dark colored, chitin, and with greatly elongated, often massive, toothed jaws, or mandibles (fig. 5).

At certain seasons of the year winged individuals which have emerged from sixth or seventh instar nymphs by a final molt may be found in the colony. They are the winged reproductives, adult males and females in approximately equal numbers. These winged reproductives, known as alates, differ greatly in size, color, and general appearance from the nymphs, workers, and soldiers (fig. 1). So different are the alates that they might well be taken to belong to an entirely different group of animals, a mistake which even the scientist has made on occasion, and one which is embedded in native languages in the tropics, where different names exist for the ordinary termites of the colony and for the winged reproductives which, as we shall see later, emerge in great swarms at certain seasons. It is these swarming winged, or alate, reproductives which are often mistakenly termed "flying ants." Distinctions between true winged ants and termites will be found in chapter 32.

At all times there is also present in any normal colony at least one pair of breeding adult reproductives, known as king and queen. These, however, are not ordinarily seen except on very careful search. In many colonies the original pair, or primary reproductives, which initiated the colony are present, and hence all members of the colony are their offspring. In other colonies, however, the reproductives discovered are of a different type from the original or primary pair, and are known as the supplementary reproductives, or supplementary king and queen. These are developed from nymphs and lack, in part at least, the pigmentation and the prominent compound eyes which characterize the primary reproductives (fig. 1*a*). These supplementary reproductives never have completely developed wings, but usually bear the rudimentary nymphal wings known as wing pads (fig. 1*e*). Supplementaries appear in colonies in which the primary reproductives have been lost, and particularly in subcolonies resulting from the isolation of groups of individuals from an established colony.

Termite colonies are said to be gynandrarchic, since they are instituted by a single pair of reproductives, the king and queen. In this regard they are in contrast to the colonies of ants, bees, and wasps, which are founded by females only, and hence are known as matriarchic colonies.

FUNCTIONS OF THE VARIOUS CASTES

The reproductive caste.—The reproductive caste performs the fundamental function of reproduction, and it is characteristic of social development among the insects, as contrasted to that in human society, that this function is relegated to a very few individuals, typically a single pair, among the hundreds or thousands of individuals making up a colony.

Other important functions of the reproductive caste are the distribution of the species accomplished by the swarming flight, the choosing of the site for the new colony, the excavation of the first galleries, and the feeding and care of the first young of the new colony. As soon as the first nymphs are old enough they take over the communal duties of food getting, construction, and care of the young. This relieves the royal pair of housekeeping duties and enables them to confine their activities to reproduction, since they are fed and groomed by the nymps and, later, by the newly developed workers.

Physogastry.—With relief from duties other than egg-laying, and with an increasing supply of food from the workers, the ovaries of the queen begin to increase in size, with a consequent increase in egg-laying powers. Correlated with this is a gradual distention of the abdomen (fig. 1*h*), old queens of certain tropical species reaching a length of five inches or more (fig. 4). Such queens lay thousands of eggs per day. The queen of a certain African species was estimated (Fuller, 1915) to lay 4,000 eggs per day. Emerson (unpublished MS) reports counting 7,000 eggs laid in one day by the queen of a South American termite, *Anoplotermes silvestrii*. The ovaries of a single queen of a Ceylon species were estimated by Bugnion (1914) to contain at one time 48,000 eggs in various stages of development. Colonies containing such queens consist of hundreds of thousands, and in some cases millions, of individuals. Emerson (unpublished MS), after careful study, has made what he believes is an accurate estimate of the population of a single colony of another South American species, *Nasutitermes surinamensis*, namely, approximately 3,000,000 individuals.

The termite colonies of the temperate zone are much smaller than this, and greatly enlarged physogastric queens do not occur in them. Here the population of a colony of wood-dwelling termites (chap. 21:II) runs into the hundreds or a few thousands, while that of subterranean termites is estimated to consist of many thousands of individuals (p. 150).

Potential immortality of colony.—A termite colony, if depending for its increase on the reproductive capacity of a single royal pair, would necessarily be subject to limitations of two types: First, its life would be dependent upon the continued life of a single reproductive pair; with their death the colony would cease to increase, gradually dwindle, and ultimately die out. Second, the effective working area of such a colony would be relatively small. Certain ant colonies move from place to place, taking their reproductives with them. The enormously enlarged queen of a colony of termites is, however, usually incapable of locomotion, and hence her range is greatly circumscribed and her location is largely determined and fixed.

These limitations, however, are overcome by the fact that in groups isolated from the main colony supplementary reproductives develop in the relatively short time of six to eight weeks. These supplementary reproductives are nymphs which, for reasons not fully understood as yet, develop into reproductives when not in contact, *i. e.*, in the same colony, with other functioning reproductives. The most satisfactory hypothesis, and one which is now being investigated experimentally, is that the reproductives secrete a substance which is distributed throughout their colony by the constant licking and food-passing which characterize the behavior of all termites. This substance is believed to inhibit for the time the development of the nymphs of the later instars into reproductives. In isolated groups, this substance being absent, the older nymphs tend to become sexually mature. Those most advanced sexually are the first to reach the stage in which they secrete the inhibitory substance, and in this way the development of other and less matured nymphs as supplementary reproductives is in turn inhibited.

Whatever the real explanation of this fascinating biological problem, the fact remains that such supplementaries play an extremely important role in the economy of the termite colony. First, they would seem to make the colony potentially immortal. Observations in nature seem to point to this condition, at least among the higher termites, the earth-dwelling species. It should be noted, however, that Dr. Kalshoven (1930), in his work on a lower, or wood-dwelling termite, the teak termite of Java, *Kalotermes tectonae*, presents evidence which he believes points to the limitation of the life of the colonies of this species, irrespective of the presence of supplementary reproductives. Supplementary reproductives are, indeed, less commonly encountered and less important among the dry-wood termites than among damp-wood and subterranean termites, but the examination of hundreds of colonies of dry-wood termites of the Pacific area belonging to several species has failed to furnish any evidence of senescent or dying colonies, except in cases plainly explained by environmental conditions, such as failing food supply, excessive moisture, or the encroachments of fungus or of subterranean termites. Among damp-wood termites supplementaries are very common and are found in groups more or less remote, but in some cases apparently not entirely isolated, from the original reproductive pair.

The supplementaries are very effective as reproductives, the supplementary queen laying eggs much more rapidly, at first at least, than does the primary queen. In our common subterranean termite, *Reticulitermes hesperus,* for example, a supplementary queen is capable of laying more eggs in a day than a primary queen lays in the first two years of the development of the colony. Supplementaries are therefore exceedingly important, not only in increasing the general termite population, but also in accelerating their widespread distribution throughout the available food material. It would seem that the numerous cases of extensive damage accompanied by the presence of alates of subterranean termites in relatively new structures are to be explained by the invasion by foraging groups which form subcolonies headed by supplementary reproductives.

Previous to swarming, the primary reproductives bear well formed wings (fig. 1*a*), which are shed at the end of the flight. The wings break off at a definite suture and leave "wing-scales," which characterize the primary king and queen, as do also the fully formed compound eyes (fig. 1*h*) and the completely chitinized and pigmented chitinous exoskeleton. Supplementary reproductives, on the other hand, lack the wing-scales and show all degrees of size, pigmentation, and development of eye and wing intermediate between conditions found in nymphs of the various older instars and the fully developed primary reproductives.

The soldier caste.—Although termite colonies live in enclosed dwellings in the earth or in wood, shut off from ordinary contacts with other animals, these fastnesses are nevertheless sometimes penetrated by enemies, and defense of the colony becomes imperative. The chief invaders are the true ants. The indi-

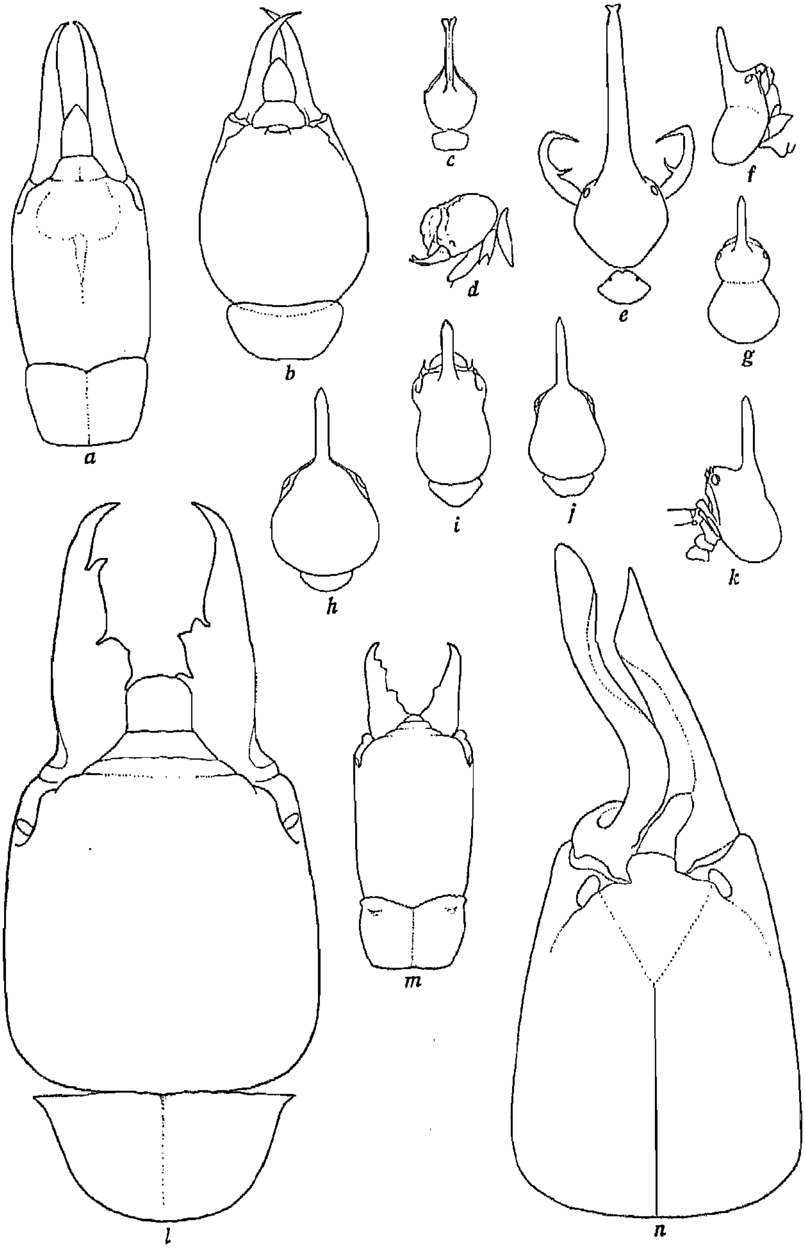

Fig. 5. Heads of soldiers of various termites in outline at approximately the same magnification (×12), showing range of size and specialized structural modification.

a. Heterotermes aureus from Arizona, with slender, toothless mandibles. *b. Coptoterme ceylonicus* from Ceylon. Note the large, anteriorly placed opening of the head gland, fro which is ejected a milky secretion, toxic to ants. *c. Rhinotermes longidens* from Panama, vidual worker or nymph, when exposed, is extremely vulnerable, and an ant will readily overcome and carry off a termite several times its size. In the natural course of events, however, the break into the closed burrow will be a small one, and the termite soldier functions admirably for the defense of such openings. Very diverse types of soldiers occur in different species (fig. 5), but most, if not all of these, are adapted to prevent the entry of enemies through a temporary breach into the colony dwelling. In all types of soldiers the head and the mandibles are greatly altered from the type found in other castes and instars. The chitinous covering of the head is thick, hard, and darkly pigmented, and the head is usually much enlarged. The mandibles are typically greatly elongated, becoming either massive, heavily toothed, crushing weapons, as in the wood-dwelling termites (fig. 5*m*), or slender, pointed, piercing weapons (fig. 5*a–b*), as in the two higher families, the Rhinotermitidae and Termitidae. In certain species, as in the genus *Capritermes* (fig. 5*n*), these mandibles are curiously twisted into spring-like snapping organs of considerable power which have been variously interpreted as functioning for leaping, for snapping dust at enemies, for making noise either to alarm the colony or frighten away enemies, or for delivering severe blows to attacking enemies, while the relatively enormous box-like heads mechanically plug up the runways.

In the powder-post termites the head is high, truncated in front (fig. 5*d*), and the mandibles reduced. Here the soldier functions as a living plug to the narrow runways of the colony.

Another commonly encountered protective device which has been highly developed by the soldiers of several widely separated groups is the use of the secretions of the cephalic gland in the center of the head to deter, stupefy, or mechanically impede attackers. This gland is feebly developed and without a pore in the wood-dwelling termites (family Kalotermitidae), but in other termites it opens by a pore, typically tiny and located in the center of the top of the head.

In those species which depend upon the use of this secretion three devices make it more effective. In the soldiers of *Coptotermes* this head pore, known as the fontanel, is greatly enlarged and is located at the extreme front of the

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small soldier, in which the adaptation to chemical warfare is pronounced. The mandibles have been lost and the upper lip greatly elongated to form a trough along which runs the toxic secretion. The large soldiers of these species retain the mandibles (see fig. 2). *d. Cryptotermes brevis* from Cuba, a specialized wood-dwelling type with reduced mandibles and head used for plugging up passageways. *e. Armitermes perarmatus* from Panama, with the head itself drawn out into a tube bearing the opening of the head gland at its tip, but retaining the mandibles. *f–k.* Nasute types in which the mandibles are vestigial and the head drawn out into a tube for chemical warfare. *f. Nasutitermes (Tenuirostritermes) briciae* from Bolivia, side view. *g.* The same, in dorsal view. *h–k.* The three types of soldiers present in all colonies of *Nasutitermes (Diversitermes) melanocephalus* from Bolivia. *h.* Large soldier. *i.* Intermediate soldier. *j.* Small soldier. *k.* Small soldier in side view. *l. Zootermopsis laticeps* from Arizona, a primitive type with massive head and large, heavily toothed mandibles. *m. Kalotermes snyderi* from the southeastern United States, with short mandibles. *n. Capritermes bodkini* from British Guiana, with massive head used in blocking subterranean passageways, and twisted mandibles used for snapping. *a, d, l, m,* after Banks and Snyder (1920); *b,* after Bugnion and Popoff (1910); *c, e, f–k,* after Snyder (1926*c*); *n,* after Silvestri (1923).

head just above the mouth parts (fig. 5*b*). In this genus the secretion is a milky white, sticky substance which serves mechanically to entangle and impede the enemy, and is reported to have a powerful chemical effect on the insects touched by it.

In many species in which there is no especial change in the shape of the head connected with the functioning of this gland, there is a more or less distinct groove to direct the flow of its secretion down the front of the head to the mouth parts, where it becomes distributed on the jaws and is thus transmitted to the enemy. This is the condition found, for example, in the species of the subterranean termites of the temperate zone belonging to the genus *Reticulitermes* and in the tropical genus *Heterotermes*. In other genera this groove is emphasized and runs out onto the labrum. This is the case with the soldiers of the genus *Prorhinotermes*, which in habit are damp-wood termites. This method is carried to an extreme in the small soldiers of the genus *Rhinotermes*, in which the mandibles are reduced and the labrum deeply grooved and very greatly extended (figs. 2*b*, 5*c*). The large soldiers of the same species (fig. 2*a*) retain the more primitive weapon of massive, toothed jaws.

In the genus *Coptotermes* the frontal gland of the soldier is enormous, filling a considerable portion of the cavity of the abdomen. The aperture of the gland is at the end of a relatively large, short cylinder located at the front of the head just above the base of the mandibles (fig. 5*b*). The copious secretion of the cephalic gland, which is viscid and milky white in color, is poured out onto the mandibles during combat. This fluid seems to function both to entangle and to stupefy enemies, particularly ants.

The use of chemical warfare has reached its climax in the soldiers of a large number of species belonging to several genera of the highest family, the Termitidae. These soldiers are typically small, agile creatures known as nasutes, with only microscopic rudiments of jaws. The head is pulled out into a long cone, known as the rostrum (fig. 5*f*–*k*), at the tip of which lies the opening of the cephalic gland, whose secretions are thrown out in long, sticky threads. These threads entangle the enemy and seemingly repel by odor or contact. That this is a successful method of protection is indicated by the fact that these nasute species are among the most successful of termites, particularly in the tropics, where they may truly be said to be dominant. *Armitermes* is a genus the soldier of which has developed this adaptation but retains the mandibles (fig. 5*e*).

It should be noted in passing that the cephalic secretion is acid in nature and is responsible for the etching of metals traversed by termites, and it is the chemical effect of this acid which is said to make possible the penetration of lime mortar by *Coptotermes* and *Reticulitermes*.

The worker caste.—The workers present [illegible] especial structural characteristics as a rule, and have much the same characteristics as to shape of head, antennae or feelers, mandibles, etc., as have the nymphs and the reproductives (fig. 1). In certain species it is difficult to distinguish them from older nymphs without wing pads, while in others a greater pigmentation of the head marks the worker caste.

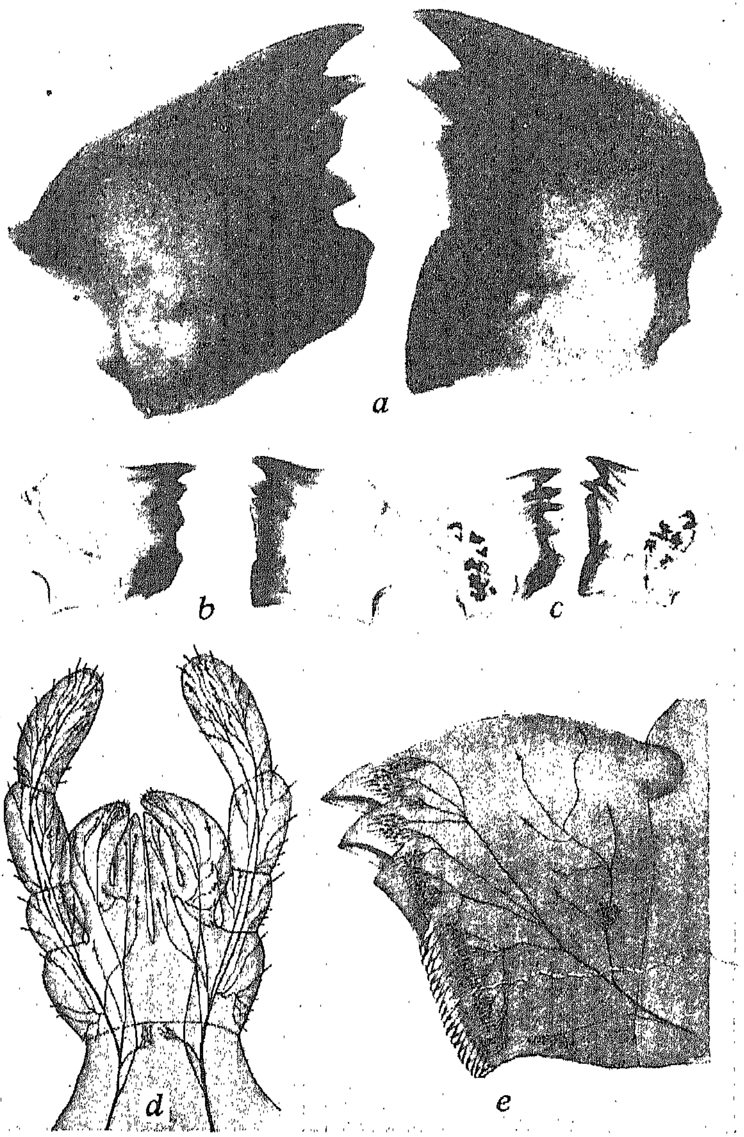

Fig. 6. Mouth parts of termites. All × 75. *a–c.* Photomicrographs of mandibles of the three common California species, showing cutting edges and teeth used in shaving thin bits of wood from the surface of the bur[illegible]

a. Mandibles of alate of *Zootermopsis angusticollis*, the common damp-wood termite. *b.* Mandibles of nymph [illegible] common dry-wood termite, *Kalotermes minor*. *c.* Mandibles of worker of *Reticulitermes hesperus*, the western subterranean termite. *d–e.* Drawings of labium, *d*, and right mandible, *e*, of *Zootermopsis angusticollis* to show nerves and peripheral sense organs as seen after special staining. From Noyes (1930).

The mandibles, by means of which the workers bite off fragments of wood, are heavy chitinous structures with toothed edges (fig. 6*a–c*) facing toward the middle and working over one another. They vary somewhat in the different groups but maintain a similar plan throughout. They are very much alike in the workers, alates, and nymphs of the same species.

The development of a worker caste whose members are destined to remain active within the colony throughout a long life has made possible the production of the populous colonies of earth-dwelling termites composed of many thousands and even millions of individuals (figs. 4, 32). On the other hand, the species of wood-dwelling termites which constitute the Kalotermitidae are without a special worker caste. Here the work of the colony is done wholly by the immature stages of the reproductives and of the soldiers (fig. 90*b*, *d*). Since the reproductives mature in approximately a year and leave the colony by swarming, and the soldiers are present only in small numbers and are incapable even of feeding themselves, it will be seen that very populous colonies are not to be expected in the family Kalotermitidae.

THE LIFE CYCLE: COLONY FOUNDATION AND DEVELOPMENT

Swarming.—Termites, being cryptobiotic animals, are as a rule negatively phototropic and positively thigmotropic; that is, they flee from the light when exposed to it, and seek the bodily contacts to be found in crevices and narrow passageways. This is especially true of the nymphs, workers, and soldiers, and is also true of the functioning reproductives and of the winged reproductives, except at certain brief periods in their life.

Winged reproductives, or alates (fig. 1*a*), appear at a characteristic period in each year in all normal colonies of two years of age or more. They arise by the last molt from nymphs of the sixth or seventh instar, which bear long wing pads (fig. 3*a*). The alates may be present in the colony for as much as three months before swarming, awaiting a certain combination of physical conditions, particularly warmth and soil moisture. When these favorable external conditions arrive, the colony as a whole is stimulated to feverish activity. The alates are now characterized by a complete reversal of instincts; instead of the strong instinct to flee the light and remain in narrow passageways, they are strongly attracted by light and seek to emerge into the open. The workers and nymphs now construct openings to the outside, thus for the moment behaving in a manner contrary to their usual deep-rooted habit of keeping the colony dwelling entirely closed. Through these apertures the alates feverishly push their way out into the open (fig. 8) and take wing for a brief flight lasting usually but a few minutes. At this time, also, the workers and soldiers are often to be seen in and outside of these openings, thus further violating their ordinary reactions to light. Whether they are simply guarding the opening and are carried out by the impetuous emergence of the crowding alates, or whether they also have temporarily undergone a reversal of tropisms remains to be determined by experiment.

The swarming of termites is one of the most interesting aspects of insect behavior. In the moist tropics the flights ordinarily occur at the beginning of the rainy season, usually after the first rains, in the early evening, either during light showers, following a rain, or when rain is impending. The swarming alates emerge at the same time over large areas where the same meteorological conditions prevail. Their numbers are almost incredibly great and, in the case of certain ground-dwelling termites, they arise in great clouds which darken the sky of late afternoon or early evening. Attracted in enormous numbers by the lights, the alates of certain species make life a burden to mankind on the evening of their swarming. Eating is impossible, since they drop in countless numbers into food and water. Indeed, the only chance for comfort is to sit in the dark, since they enter the clothing in great numbers if one sits near a light, and, while quite unable to do any real harm, their excited crawling over the skin is not pleasant.

The author has described (1929*b*) the swarming of *Coptotermes vastator* in a house in Manila. Weather conditions were typical of the early rainy season in May. It was cloudy and oppressive, with very slight showers and thunder in the distance. Heavy showers fell later during the night. Swarming took place successively from various parts of the house, beginning at dusk. Dirt galleries not present, or at least not conspicuous, previously, had been built out at several points along door posts, etc. From projecting portions of these, as well as from cracks between nearby boards, the winged adults were pouring out when first observed. Guarding these openings were numerous soldiers, making a solid line with heads facing out. These seemed to have nothing to do with the actual emergence of the adults but to act as a guard to prevent entry of that terrible enemy of the termite, the true ant. Many of these soldiers as well as a few workers were carried out in the rush of emerging alates. In one room where the floor had been badly attacked the alates swarmed through the cracks in immense numbers and formed a struggling mass about three feet in diameter and two inches deep. The sound made by the wings of the thousands of emerging, struggling, and flying individuals was very suggestive of the soft yet pervasive sound of a first heavy snow. The emerging alates flew at once toward the nearest or strongest source of light, thus demonstrating their remarkably strong positive phototropism. They were led throughout the house by turning lights on and off in series. When two lights of the same magnitude were burning in adjoining rooms, the lowest members of the swarms about each light were not directly under either light, but each swarm spread outward toward the floor in the direction of the other light, the positions taken being a result of the attraction of the two lights. This could be clearly demonstrated by doubling the lights at one point, when this living curve moved toward the stronger light until a new equilibrium was attained considerably nearer the brighter light.

The alates were strong and rapid flyers. A great cloud of thousands about the light near an open door would sweep out of the door in a few moments as soon as the lights were turned off. This movement was especially rapid when an outdoor light was switched on and the inside light was switched off. What became of them after they left the house was not determined. That they fell prey in great part to ants, birds, lizards, bats, rats, etc., seems certain, as has been observed to be the case on many occasions and in many regions.

The emergence at any particular point seemed to last not longer than twenty minutes, but termites were emerging at some points for the better part of an hour, and a few still congregated about the lights for an hour after that. Similar swarms occurred at many points of the city, and no doubt over a much wider area under similar meteorological conditions.

In regions where the rains coincide with a period of cold nights, as is the case in the temperate regions, day flying occurs, as would be expected. Throughout most of their geographic range alates of *Reticulitermes* are developed in the colonies only in early spring. The moisture of winter or early spring rains is favorable to swarming, but not until the temperature rises to a certain point are all requirements for emergence met. This will naturally be during the day sometime in late April or early May. On the Pacific Coast alates appear in the colonies during the summer and swarm after the first autumn rains. A less important swarming also occurs in the spring.

Day-flying species are characteristically darkly pigmented. This is the case with nearly all species of the genus *Reticulitermes* and also with the common dry-wood termites, *Kalotermes minor,* which are also day-fliers. [For an account of the swarming of *K. minor* see pages 208–211 of this report.] *R. hesperus,* the western subterranean termite, may confidently be expected to swarm in great numbers between 10:00 A.M. and 3:00 P.M. over wide areas in California on the first warm day after the first rain of the autumn. The black, swarming alates of this species are often mistaken for flying true ants and are popularly but incorrectly so designated. [For an account of the swarming of *R. hesperus* see pages 151–152 of this report.] At the time of their swarming their bodies and wings are to be found on every hand in wayside puddles and along damp roadsides and sidewalks in all parts of coastal California (fig. 8*b*). On such a swarming day San Francisco was traversed by us in three directions. An inspection made at each corner in all three traverses showed in every instance either swarming alates, crawling pairs, individuals caught in moisture, or the shed wings.

Through the cooperation of the plant staff of the California and Hawaiian Sugar Refinery at Crockett, California, we have an interesting picture of the prevalence of the western subterranean termite in this small town in north central California, and the extent of the swarming on the first favorable day. Fifteen men supplied with vials were assigned to given localities. They were to be ready for service when notified that the expected day had arrived. October 30, a clear day following rain the previous day, met the requirements and the men were sent to their stations. Swarming occurred from 10:00 A.M. to 2:00 P.M. The number and location of swarming colonies found are indicated on the map (fig. 7). One hundred and eleven such separate swarmings were found on that day, indicated on the map by solid circles. On the next day only seven colonies were found swarming, as indicated on the map by circles containing an x. It is interesting to note that none of these were in the same localities as those taken the first day. No attempt was made to cover the entire town, and therefore the absence of swarms in certain areas of the map has no significance.

When the onset of the rains is greatly delayed, as in 1930, the pent-up swarming urge results in attempts at swarming when the temperature is so low as to make flight impossible. The result is accumulations of alates around the emergence holes, as shown in figure 8*a*.

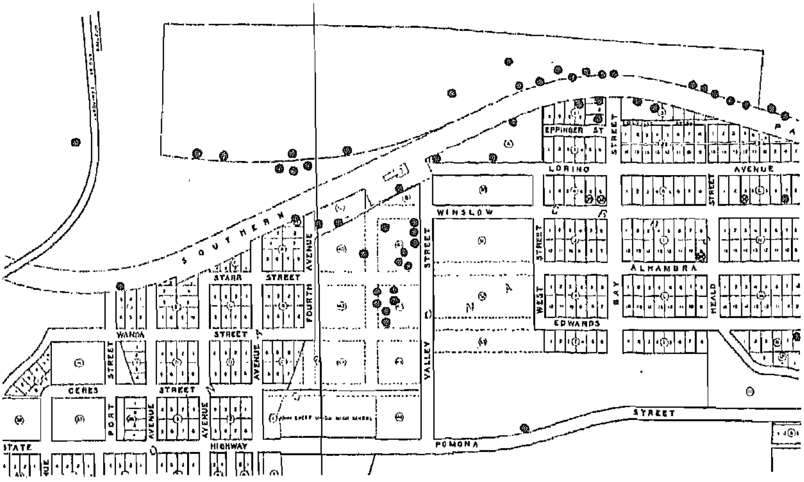

Fig. 7. Map of a small town in California showing the location of the different swarms of *Reticulitermes* which were noted on the first and second days of an annual swarming. The solid circles indicate the locations of swarming flights seen on the first day, and the crossed circles those noted on the second day.

In the desert area, where the rains are rare, alates may remain within the colony for many months awaiting a proper combination of moisture and temperature. Here nights are cool and days very warm for much of the year, and hence the termites are chiefly day-fliers. When rains come at times of great heat the situation is met by swarming in the very early morning. It will readily be seen that once the necessary moisture is present, swarming occurs at such time during the day as the requisite temperature is reached. The early morning swarming in desert country is described as follows for Silvestri's Amitermes, *A. silvestrianus* Light, by an eye-witness, L. F. Strehlke, of Palm Springs, California (Light, 1932*a*).

> These few specimens were gathered on August third, two days after a very heavy rainfall, during which an inch of rain fell in one hour. I was sleeping out of doors because of the great heat. My bed was a cot situated in a cement-floored court between two buildings. When I awoke at about five o'clock in the morning I was greeted with the very interesting sight of thousands of insects flying to and fro three feet to six feet above the ground. The flight was so slow and sluggish that I had no difficulty in reaching up my hand from the cot on which I was lying to capture them at will. These I preserved and are the ones I am turning over to you. Just before sunrise these insects began to drop to the ground or pavement. After dropping they would make a few trials to fly at which they would succeed only after a

fashion. They would soon abandon their attempts to fly and would crawl about aimlessly and then of a sudden drop their wings. The entire wing equipment would fall from the body at once. At this stage the insect would go about excitedly until it mated, which seemed almost immediately. The two would then crawl rapidly about, one following the other in such close formation as to have the appearance of one insect. They would run about nervously in no fixed direction but seemingly seeking shelter of any crack, fissure, or deep depression that might occur in the cement pavement. Shortly after sun-up, about thirty minutes as I remember it, I was unable to find a single live insect. The only evidences remaining of their recent visitation were the countless thousands of tiny wings covering the pavement.

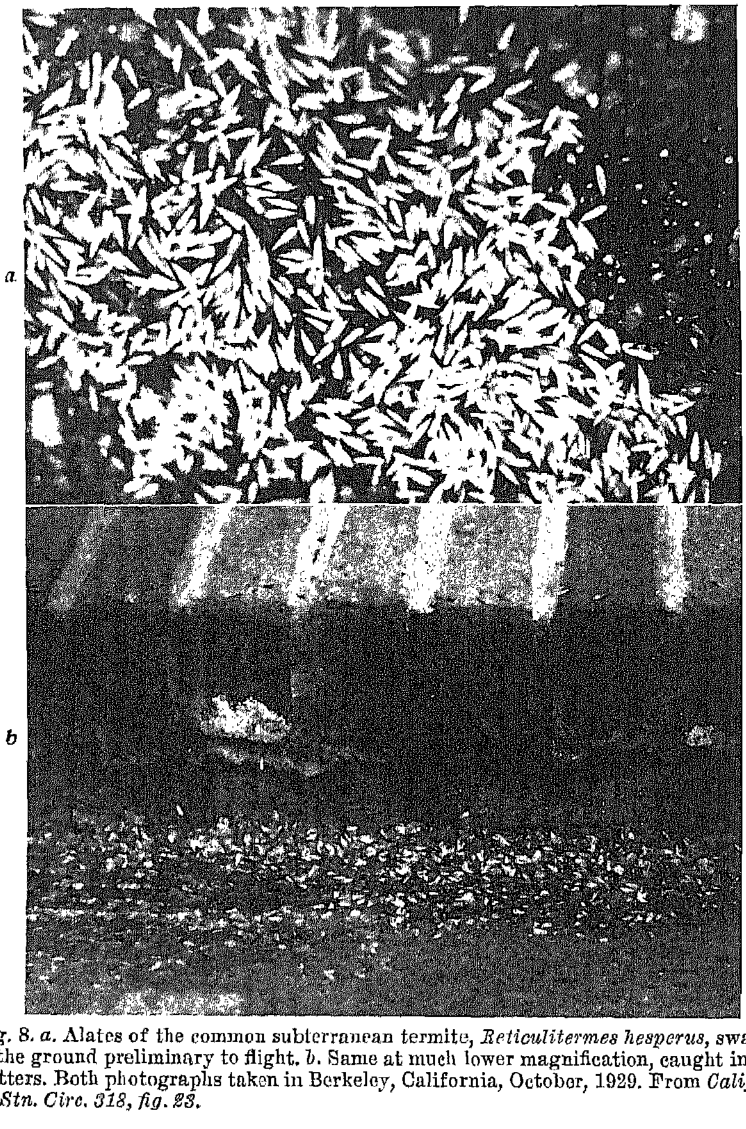

Fig. 8. *a.* Alates of the common subterranean termite, *Reticulitermes hesperus,* swarming over the ground preliminary to flight. *b.* Same at much lower magnification, caught in water in gutters. Both photographs taken in Berkeley, California, October, 1929. From *Calif. Agr. Exp. Stn. Circ. 318, fig. 23.*

Flight.—Termite species differ widely in the speed and duration of flight of their alates and in the distances traversed while swarming. In general, the wood-dwelling termites are stronger fliers than the earth-dwelling species and capable of more extended flights. It has been impossible to determine the full length of such flights, but there seems every reason to believe that *Kalotermes minor* travels distances of half a mile or more (pp. 212–213). The damp-wood termites (*Zootermopsis*) have a strong, well-directed flight. They change direction at will, alight to investigate structures, and then resume flight.

Termites of higher species often have much weaker powers of flight, and except when wind-carried, seem to cover relatively short distances in the swarming flight. This is true of *Reticulitermes,* large numbers of which often end their flights within a few feet of the point of emergence. Nothing definite has been known heretofore as to the role wind and air currents may have in their distribution. Dr. T. E. Snyder, Senior Entomologist of the U. S. Bureau of Entomology, has kindly made possible the use of extremely important data on this point. Alates of *Reticulitermes virginicus* Banks were taken by aeroplane at Tallulah, Louisiana, at altitudes of from 20 to 3,000 feet, as listed in Table 2.

TABLE 2

AEROPLANE COLLECTIONS OF ALATES OF *Reticulitermes virginicus* AT TALLULAH, LOUISIANA

Date	Hour	Altitude in feet
April 26, 1929	2:59 P.M.	1,000
May 15, 1929	10:34 A.M.	200
April 3, 1930	10:23 A.M.	20
April 5, 1930	1:49 P.M.	200
April 5, 1930	1:38 P.M.	1,000
April 15, 1930	10:44 A.M.	200
April 15, 1930	3:30 P.M.	200
April 16, 1930	9:44 A.M.	2,000
April 22, 1930	1:21 P.M.	3,000
April 22, 1930	2:56 P.M.	1,000
May 22, 1931	2:20 P.M.	2,000

This leaves no room for doubt that swarming alates are at times carried by winds for a distance of several miles, and lends emphasis to the belief that the alate of *Reticulitermes,* while it may not be of great importance in the establishment of new colonies in occupied territory, performs a significant function in the occupation of new territory (p. 157).

The swarming flight seems to be a necessary preliminary to the series of events leading to the founding of the new colony. Light (in press), working with *Paraneotermes simplicicornis,* the desert damp-wood termite (chap. 25), found that when alates which had not swarmed were assorted in pairs, neither loss of wings nor pairing occurred. Attempts to accomplish artificial swarming by placing the alates in glass dishes in the sun failed. They leaped into the air and even made short flights, but this was evidently not sufficient, since no indications of pairing followed. When, however, they were placed in the sun in a swarming cage 1½ feet × 2½ feet × 1 foot, with both broad surfaces open and covered with cheesecloth, the group burst immediately into a frenzy of energetic reactions beginning with short, rapid, nervous flights from side to side of the box, and ending with their congregation at the point of maximum illumination. Three minutes after exposure some were dealated. Immediately on alighting from the short flights, violent efforts were made to get rid of wings, which were suddenly and violently thrown out from the body at an unusual angle. There were violent twistings and turnings and rubbings in corners, and short rapid flights along the surface, striking outspread wings against it. One alate was seen to use a crack in the wood very effectively in rubbing off the wings. Within eight minutes after their introduction into the cage all were rid of their wings. Nervous racing about began as soon as dealation was completed, due to two urges entirely foreign to the alate of a few minutes or seconds before. These were the mating urge and the urge to escape the light which had been so strongly sought just before. The usual pairing phenomena were at once in evidence, namely, the uplifted female abdomen and the tandem pairs. By the time loss of wings, or dealation, was complete for the group only the last individuals to accomplish it were in sight, and these disappeared at once into the spaces between the cheesecloth and the boards below and into the cracks between the boards. Even those unpaired responded to the cryptobiotic urge thus strongly reasserting itself.

Dealation.—Dealation, or the automatic dropping of the wings at the time of swarming, is the second step in the chain of important events initiated by emergence of the sexually mature alates from the swarming apertures. In the case of some individuals of certain species dealation may actually occur in the air. In most species, however, dealation occurs almost immediately on alighting from the swarming flight, as described above. For a description of the process as seen in *Kalotermes minor* see page 214.

Pairing.—Dealation is normally followed by pairing. The female termite, on alighting from the swarming flight, takes up a characteristic posture with the tip of the abdomen uplifted. This is accompanied by rapid, excited movements, both during dealation and following it, which have been interpreted as "attracting devices" (Fuller, 1915). There is much evidence to show that this posture and possibly these movements have to do with the emission of an attracting odor. However this may be, there is a great sex attraction at this time and individuals of opposite sexes meeting one another usually arrange themselves in pairs with the female in front and the male behind, the latter following all the sudden twists and turns of the female, keeping his antennae playing on the tip of her abdomen, presumably because of the odor emitted by her. For a detailed description of the pairing of the common drywood termite, *Kalotermes minor*, see page 214.

Infestation and establishment of the new colony.—Only for the few brief moments of emergence, swarming, and pairing do the alate termites revert to the ancestral, free-living habits characteristic of most insects of today. Once dealation and mating are accomplished there is again a sudden reversal of tropisms, the light-fleeing, crevice-seeking instincts reasserting themselves.

The pairs now seek a crack or crevice in suitable wood, if they are wood-dwelling termites, or dig into the earth itself or between some piece of wood and the earth, if they are earth-dwelling species. In either case they dig themselves in and seal the opening, thus returning to the cryptobiotic habit for the duration of their life and the life of the colony they institute.

Zootermopsis alates, if artificially paired, will ultimately dealate and mate (chap. 24). For most termites, however, normal flight and dealation immediately thereafter are necessary preliminaries to pairing. Indeed, this whole series of instinctive reactions, including flight, dealation, pairing, and infestation, form a necessary chain of events; any break in the chain inhibits the succeeding steps. This is well exemplified by Light's findings (1929*b*) with regard to the swarming of the Philippine milk termite, *Coptotermes vastator*. Alates were caught in the evening in tin boxes moved back and forth through the swarms under lights. When the boxes were opened in the morning it was found that neither dealation nor pairing had occurred among the captured insects, though common among those not interrupted in the chain of nuptial events.

Among bees and ants the swarming flight is a mating flight during which copulation takes place. Among termites, however, neither the reproductive organs nor the sexual instinct are entirely mature on emergence, and the first copulation occurs some days after pairing. Copulation occurs at intervals throughout the life of the pair (p. 153).

The first eggs of the primary queen are relatively few in number and hatch in from thirty to fifty days into nymphs, which pass rapidly through several instars, emerging finally as workers, or workers and a very few soldiers. These nymphs, and the workers and soldiers to which they give rise, progressively assume the communal duties and thus the completed and expanded social regime is initiated.

Much remains to be learned as to the length of life of individual termites, the rapidity of increase in population of the colony, and the length of life of the colony as a whole. The ability of the termite colony to develop supplementary reproductives from among their own number would seem to make the colony potentially immortal. Kalshoven (1930), in his studies of the termite *Kalotermes tectonae,* which attacks teak trees in Java, came to the conclusion that a colony became senescent and died out in less than twenty years. The field observations of the Termite Investigations Committee, however, have not produced any evidence indicating the existence of senescent colonies. Dwindling colonies were rarely encountered; when found, their poor condition was attributable to failing food supply, unfavorable moisture conditions, and perhaps in some instances to attack by ants. We seem justified, therefore, in thinking of the colony as continuing indefinitely, the size of the individual colony being limited by a number of factors, important among which are the available food supply and the tendency of the outlying portions of large colonies to develop their own supplementary reproductives and become separated from the parent colony.

CHAPTER 4

SOME FACTORS LIMITING THE DISTRIBUTION OF TERMITES

BY

O. L. WILLIAMS

A knowledge of the relationships which exist between termites and their environments has, aside from its purely scientific value, a definite and important practical value. It is well known that different kinds of termites occupy different and more or less clearly defined areas characterized by various sets of ecological conditions. It is also well known that various kinds of termites usually differ from one another with regard to their food habits, swarming habits, rate of increase in population, adaptation to the various physical features of the environment, and other factors of similar kind. Only when armed with a thorough knowledge of the habits of different kinds of termites and their specific environmental adaptations and limitations is it possible to solve the problems of termite control, to determine the extent and nature of any given local termite problem, and to predict what the termite problems of the future are likely to be. Thus the study of the ecology of termites comes to be of both scientific and practical interest. The impossibility of making an exhaustive study of the ecology of each of the economically important kinds of termites hardly need be mentioned. A complete study of this sort can result only from the concerted efforts of a number of investigators for many years.

The Termite Investigations Committee undertook a study of some of the more important ecological factors which appeared to be concerned in the distribution of termites, more particularly those concerned in the distribution of the subterranean termites *Reticulitermes hesperus* and *R. tibialis*, especially in the soil. In the following paragraphs the results of these investigations are briefly summarized.

Reticulitermes hesperus and *R. tibialis* overlap but slightly in their distribution. The former species is characteristic of more moist regions, the latter of more arid regions. This at once suggests that soil moisture may be one of the controlling factors in the distribution of these two termites. Inasmuch as both species are subterranean in habitat, the first phase of the investigation dealt with the soil moisture requirements of each. An extensive series of experiments revealed a difference between the two as regards their minimum moisture requirements. *R. hesperus* was found to require 1.0 per cent of moisture by weight in sand, and 3.8 per cent in sandy loam, while *R. tibialis* required 0.8 per cent of moisture in sand and 3.4 per cent in sandy loam.

This difference, though slight, is probably sufficient to be of importance in the distribution of the two species. Both species tolerated soil saturated with moisture, except that they were killed by the rapid accumulation of carbon dioxide coincident with high moisture content. These tests revealed the probable importance of the carbon dioxide factor, considered more in detail below.

The moisture content of the food of subterranean termites is usually directly dependent upon the moisture content of the soil, as the food is usually on or in the ground. Preliminary experiments on the required minimum amount of moisture in the food of *Reticulitermes hesperus* and *R. tibialis* showed that in the case of filter paper (used as food because of its uniform physical and chemical make-up) at least 18 per cent of water was essential for both species. When less than that amount of water was present, both species died, but *R. hesperus* was killed somewhat the more rapidly of the two. It is believed that this differential death rate may prove significant; refinement of methods probably will show a lower required moisture content of the food for *R. tibialis* than for *R. hesperus*, corresponding with the difference in minimum soil moisture requirements of the two. Both species thrive on filter paper saturated with water.

An apparatus was devised for testing the reactions of termites to a humidity gradient. Both *Reticulitermes hesperus* and *R. tibialis* showed a strong preference for a saturated atmosphere. This reaction corresponds well with the observed fact that in cavities in soil having the minimum amount of water necessary to the survival of both species of *Reticulitermes* a condition of saturation exists. Obviously, both species are accustomed to live in an atmosphere having a relative humidity of 100 per cent. Several other species of termites were tested in the humidity gradient apparatus, with interesting results. Two species of *Zootermopsis*, two of *Amitermes*, and one each of *Paraneotermes* and *Heterotermes* all showed marked preferences for a saturated atmosphere. *Kalotermes minor* showed a less clearly marked reaction, but apparently prefers a moist atmosphere, while *K. hubbardi* showed a remarkable indifference to the humidity gradient. The two species of *Kalotermes* are dry-wood forms, while the two of *Zootermopsis* are damp-wood forms, and the others mentioned are all subterranean. These reactions correspond well with the fact that the *Kalotermes* species frequently live in a relatively dry atmosphere, the other species probably always in a moist atmosphere. Dessication experiments showed that *K. minor* resists dessication more successfully than *Zootermopsis angusticollis, Reticulitermes hesperus*, or *R. tibialis*.

Inasmuch as the carbon dioxide content of the soil atmosphere varies directly with the moisture content of the soil, it might be expected that *Reticulitermes hesperus* is adapted to a higher carbon dioxide content than is *R. tibialis*. Experiments were made to determine the resistance of the two species to high carbon dioxide contents. It was found that a considerably greater amount of carbon dioxide (40 per cent) was required to inactivate *R. hesperus* than *R. tibialis* (30 per cent) in a given length of time (50–60 hours); also, that a greater amount was required to kill the former than the latter in a given length of time, and that after inactivation *R. hesperus* was able to recover much more rapidly than *R. tibialis*. These experiments indicate the importance of high moisture content of the soil as a limiting factor in the distribution of these two species, since carbon dioxide varies with the moisture content, and *R. hesperus* and *R. tibialis* differ in their toleration of carbon dioxide. Thus both low and high soil moisture contents appear to serve as controlling factors in the distribution of these two subterranean termites.

There is little doubt that other factors than moisture are involved in the distribution of *Reticulitermes*. The temperature factor has not been studied extensively and probably will prove to be involved. The soil factor, apart from moisture, may prove important. The factors concerned in the distribution of other kinds of termites have been studied much less extensively than for *Reticulitermes*, and many important ecological problems in addition to the factors controlling distribution remain to be studied.

CHAPTER 5

THE EXTERNAL ANATOMY OF TERMITES

BY

S. F. LIGHT

Termites are insects. The basic plan of the insect body is the familiar one seen in such common insects as the grasshopper or the cockroach. The body is relatively small and elongated and is divided by constrictions into three important regions, the head, the thorax, and the abdomen. Externally it is covered by a relatively stiff exoskeleton of secreted horny material known as chitin. This exoskeleton is divided into a characteristic number of ring-shaped areas arranged in a linear series, which mark externally the divisions of the body, known as segments or somites. These body segments are much more distinct in the segmented worms, the supposed ancestors of the insects and other arthropods, than in these highly modified forms. Six such somites are supposed to be fused to form the head of an insect, four of them bearing appendages, the antennae and the mouth parts (mandibles, labium, and maxillae). The thorax clearly consists of three somites, each of which bears a pair of legs, and the last two of which bear each a pair of wings in the perfect insect. The abdomen is considered to consist of eleven segments and a terminal region known as the telson, though but nine or ten segments are readily identifiable. Appendages are lacking on the somites of the abdomen except at the posterior end, where the jointed cerci (fig. 14) may represent them.

The internal body plan is characterized by (1) a ventral, segmentally ganglionated nerve cord in thorax and abdomen (fig. 19 *(34)*) connected with the dorsally located brain by commissures running around the oesophagus (fig. 19 *(33)*); (2) a dorsally located tubular heart (fig. 18 *(27)*) between which two structures run; (3) the alimentary canal. The heart is not connected with a series of veins and arteries as in many animals, such as the segmented worms and the vertebrates, but opens directly into the irregular series of cavities surrounding the muscles and visceral organs of the body. The cavity about the organs, therefore, is a great blood space known as the haemocoele, and is not comparable to the cavity of the body in the vertebrates or the segmented worms known as the coelome.

For further discussion of the anatomy of insects in general the reader is referred to such standard texts of entomology as Imms: *Textbook of Entomology,* or Comstock: *An Introduction to Entomology.*

The basic structure of the termites has remained fairly true to the fundamental insect type. The thoracic somites are not greatly coalesced, the abdominal somites have been little, if at all, reduced in number, and have retained their freedom of movement, and the mouth parts are generalized, with biting mandibles (fig. 9*b*) and unspecialized maxillae, labium, and labrum (fig. 10*c–e*).

Within the order Isoptera, which includes all the termites and no other insects, there is, of course, a considerable diversity of structure, but the fundamental plan has undergone very little alteration. The best general account in English of the external anatomy of termites is that of Imms (1925), based largely on *Archotermopsis wroughtoni,* a primitive termite found in the lower Himalayas in India. More special accounts are those of Crampton (1914), Snodgrass (1909, 1927, 1928), Fuller (1924), Imms (1919), and Holmgren (1909, 1911).

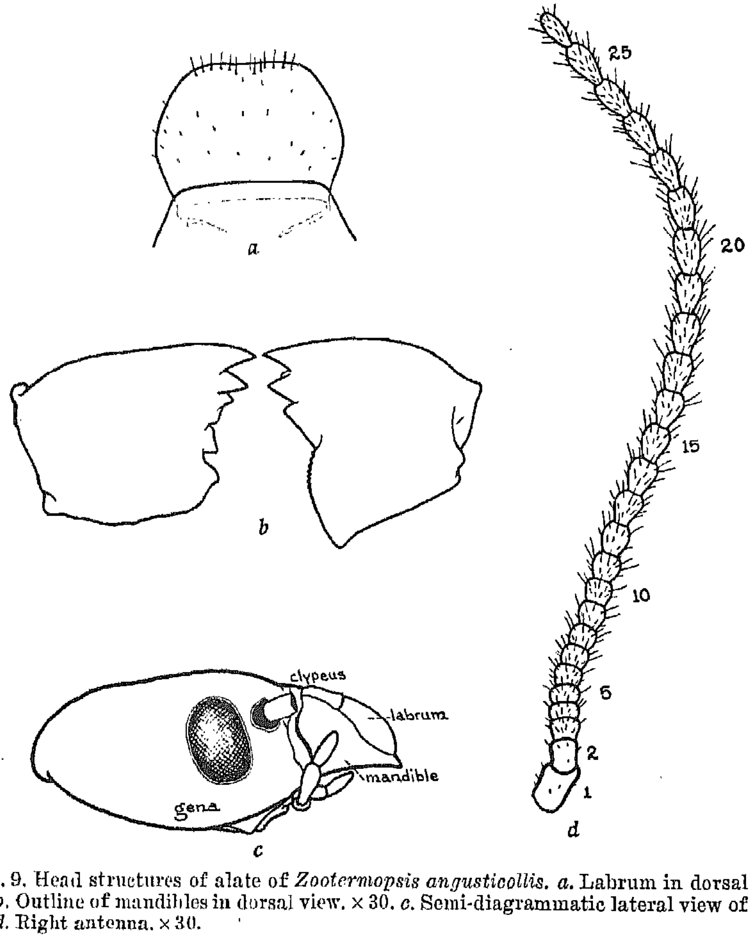

Fig. 9. Head structures of alate of *Zootermopsis angusticollis. a.* Labrum in dorsal view. × 24. *b.* Outline of mandibles in dorsal view. × 30. *c.* Semi-diagrammatic lateral view of head. × 15. *d.* Right antenna. × 30.

For our present purpose it seems feasible to confine discussion largely to a single species, the common damp-wood termite of the Pacific region of North

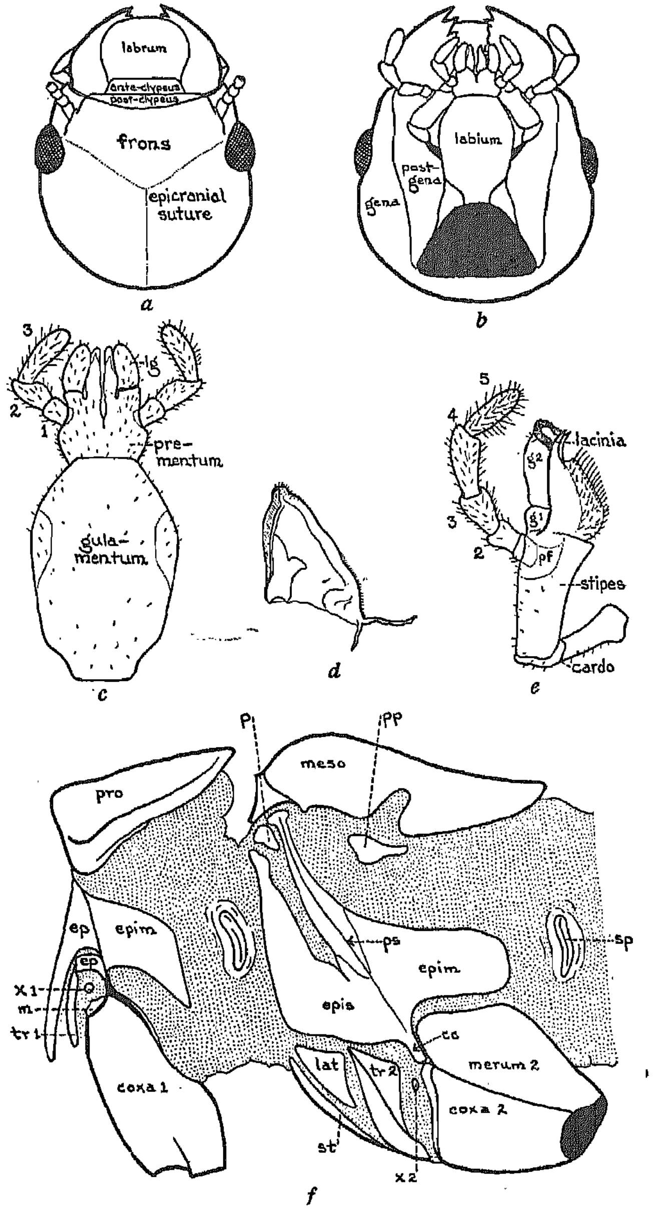

Fig. 10. *a–e.* Head and mouth parts of the alate of *Zootermopsis angusticollis.*

a. Diagrammatic dorsal view of the head, × 23, showing black compound eyes. Two structures found in many termites are absent, namely, a pair of tiny single eyes known as ocelli, each located near one of the compound eyes (see fig. 1*a*), and the fontanel or opening of the cephalic gland near the center of the head. *b.* Ventral view of head. × 23. *c.* Ventral view of labium. × 50. *lg,* paraglossa of ligula; *1, 2, 3,* segments of labial palpus.

(Concluded on page 48)

America. *Zootermopsis angusticollis* (Hagen). It is relatively primitive, is larger than most termites, is abundant in its range, and is destined to become an important laboratory animal. Save in minor details, its structure agrees with that of the other termites dealt with in this report. Sumner (1933) has investigated the external anatomy of *Zootermopsis angusticollis* (Hagen). Her paper, with figures, has been drawn upon for the ensuing brief account.

The discussion and illustrations will deal largely with the winged form, the perfect insect, which has well developed compound eyes and wings, and is covered with a well developed, pigmented chitinous exoskeleton. From these the nymphs, workers, if any, and supplementary reproductives differ chiefly in incompleteness of development. They have thinner unpigmented exoskeletons, the wings are entirely absent or represented by rudiments, and, depending upon the stage of development represented, the eyes are either almost entirely lacking or, at most, are very incomplete and, except in certain late nymphal stages, unpigmented. The antennae also contain fewer segments. The soldier represents a nymphal stage, but with greatly enlarged and heavily chitinized head and mandibles.

Coming back to the external anatomy of the alate of *Zootermopsis angusticollis* as a typical termite, we find the head to consist of a brown, heavily chitinized, flattened capsule, rounded behind and narrowed in front, when seen from above (fig. 10*a*). On its sides near the front are located the large compound eyes, and attached to its anterior surfaces are the upper lip, or labrum (figs. 9*a*, *c*; 10*a*), and four pairs of appendages: (1) the antennae, or feelers (fig. 9*d*); (2) the so-called labium below (fig. 10 *b*, *c*); (3) the mandibles (fig. 9*b*) concealed by the labrum above and the labium below; (4) the maxillae, also located below (fig. 10*b*, *e*). The labrum, mandibles, labium and maxillae, known together as mouth parts, perform sensory and mechanical functions in connection with feeding. Between the labrum and the head capsule are two articulating regions, the postclypeus and the anteclypeus (fig. 10*a*), the latter being very thinly chitinized and mobile, making possible the movement of the labrum.

The thorax, consisting of three segments (fig. 11), prothorax, mesothorax, and metathorax, bears a complicated set of chitinous plates whose nature and nomenclature are given in figures 10*f*, 11, and 13*c*. These serve partly for protection, but chiefly for attachment and fulcra for the wing and leg muscles. Especially noticeable is the dorsal shield of the prothorax, known as the pronotum (figs. 10*f*, 13*c*). Located in the soft membrane on the sides of each thoracic segment between the chitinous plates are the external openings, or spiracles (*sp*, fig. 10*f*), of the long, branching, internal respiratory tubes known as tracheae, which carry air to all parts of the insect's body.

(Fig. 10. d–e. Continued)

d. Hypopharynx, or lingua, seen from side. × 50. *e.* Ventral view of left maxilla. × 50. *pf*, palpifer; g^1, g^2, proximal and distal segments of galea. *f.* Cervicum, prothorax, and mesothorax in lateral view. × 25. *cc*, coxal condyle; *epim*, epimerum of pro- and mesothorax; *epis*, episternum of mesothorax; *ep*, episternum of prothorax; *lat*, laterosternite of mesothorax; *meso*, mesonotum; *m*, merum of prothoracic coxa; *pro*, pronotum; *p*, second parapteron; *pp*, post parapteron; *ps*, pleural suture; *sp*, spiracle; *tr 1, 2*, pro- and mesothoracic trochantine; *x 1, 2*, pro- and mesothoracic accessory coxal sclerite.

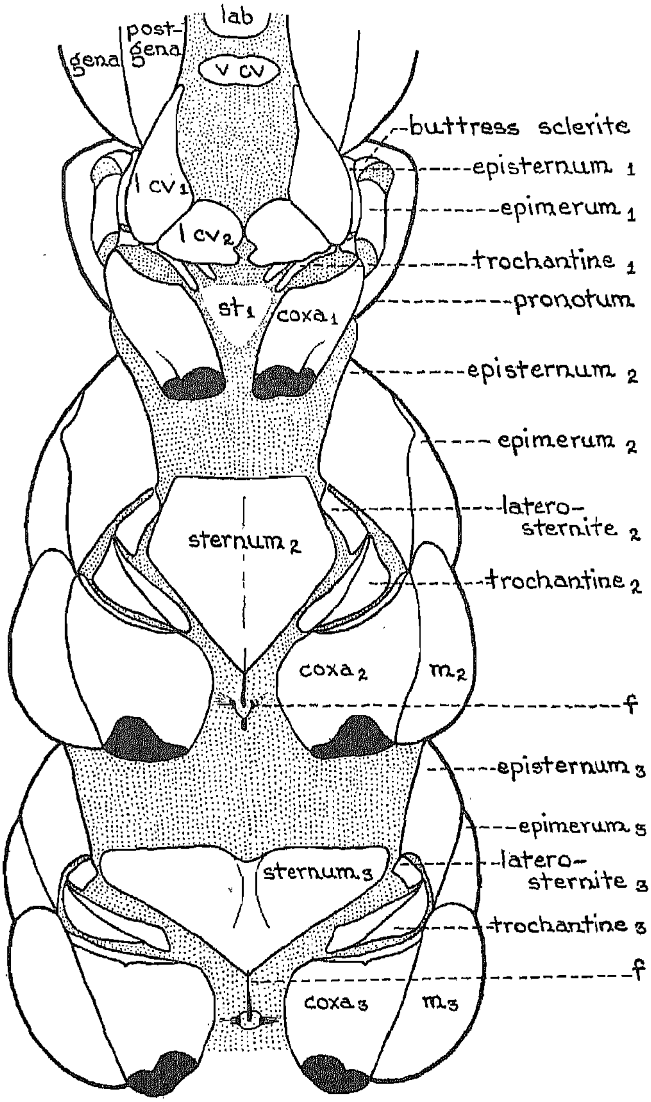

Fig. 11. Diagrammatic ventral view of thorax of alate of *Zootermopsis angusticollis*. ×25. *f*, furca; *lab*, labium; *l* cv_1, anterior lateral cervical sclerite; *l* cv_2, posterior lateral cervical sclerite; *m 2, 3*, meso- and metathoracic merum; *st 1*, prosternal region; *v cv*, ventral cervical sclerite.

Each leg is composed of five chitin-covered divisions, or segments (fig. 13*a*), jointed with each other. The last, known as the tarsus, is further subdivided into four or five smaller segments, the last of which ends in a pair of claws by means of which the termite clings to microscopic irregularities in surfaces. This ability is remarkably developed in the soldier caste.

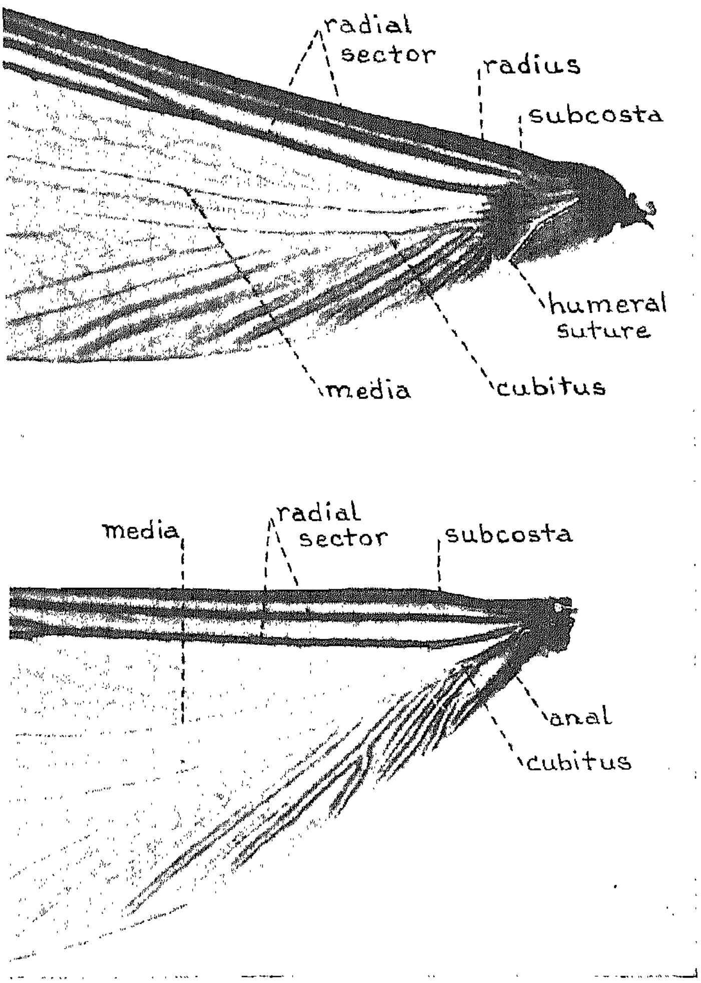

Fig. 12. Photomicrograph of bases of left fore- and hind-wings of *Zootermopsis nevadensis* to show venation, with nomenclature of wing veins. × 12. The upper of the two veins here designated together as *radial sector* is ordinarily designated in descriptive literature as the *radius*.

The thin membranous wings are longer than the body (figs. 1*a*; 89*a*). They are similar in size and venation; hence the name of the order, Isoptera. At rest they are held horizontally over the body (fig. 1*a*). Figure 12 gives the

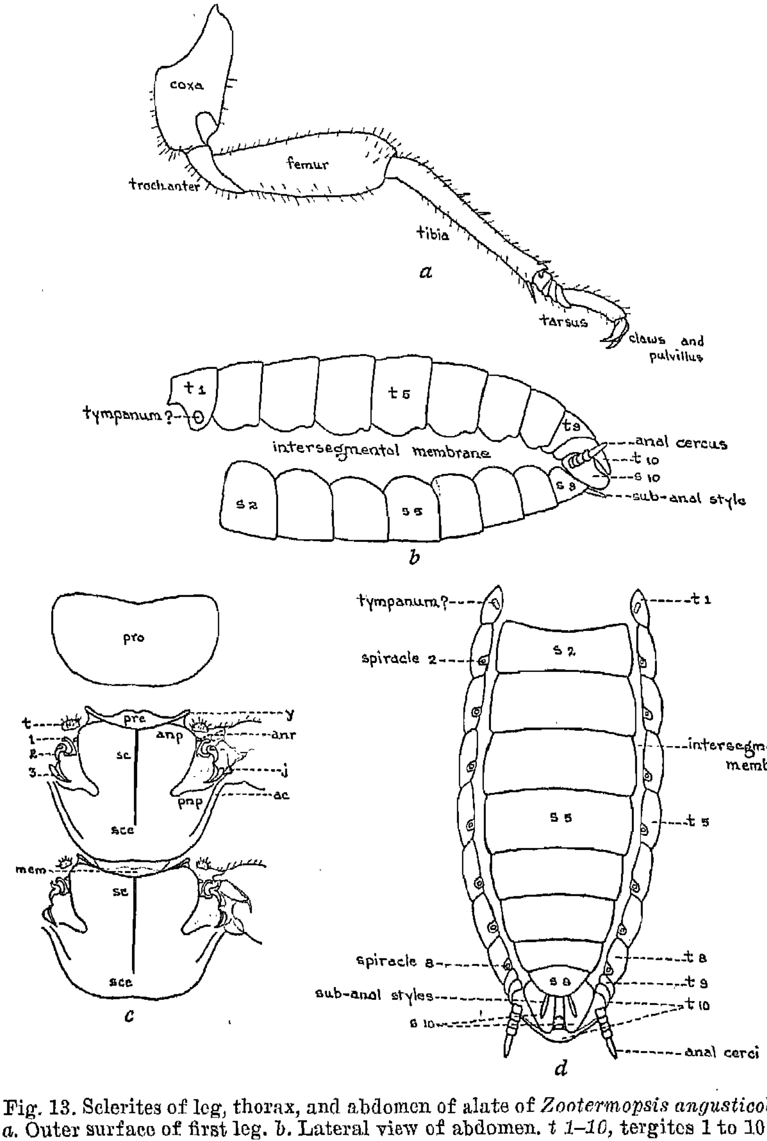

Fig. 13. Sclerites of leg, thorax, and abdomen of alate of *Zootermopsis angusticollis*. × 10. *a*. Outer surface of first leg. *b*. Lateral view of abdomen. *t 1–10*, tergites 1 to 10; *s 2–10*, sternites 2 to 10. *c*. Thorax in dorsal view. *1*, *2*, *3*, first, second, third axillaries, or winged sclerites; *ac*, axillary cord; *anp*, anterior notal process; *anr*, end of anterior notal ridge; *j*, jugum; *mem*, membrane; *pnp*, posterior notal process; *pre*, prephragma; *pro*, pronotum; *sc*, scutum; *sce*, scutellum; *t*, tegula; *y*, yoke of prephragma. *d*. Ventral view of abdomen. *t 1–10*, tergites 1 to 10; *s 2–10*, sternites 2 to 10.

names and location of the main veins. The upper of the two veins there included as radial sector is ordinarily designated the radius in systematic descriptions.

As described elsewhere (p. 274), the wings are broken off at the humeral sutures (fig. 12) after the swarming flight, and the first form reproductives, thereafter known as king and queen, bear the stubs of the wings, which are known as wing scales (fig. 1*b*, *h*).

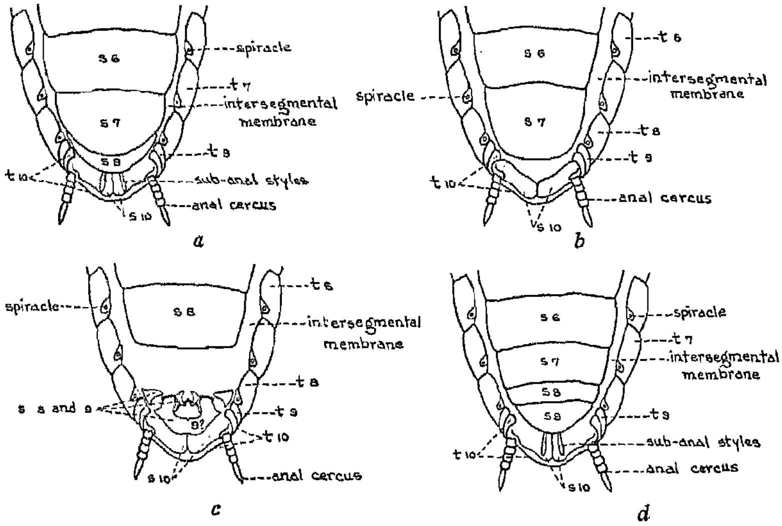

Fig. 14. Structures of the ventral surface of the tip of the abdomen of *Zootermopsis angusticollis*. *a*. Of female soldier. *b*. Of female alate. *c*. Of female alate with seventh sternite removed. *d*. Of male soldier. *t 6–10*, tergites 6 to 10; *s 6–10*, sternites 6 to 10. All × 10.

The abdomen is covered dorsally by a set of chitinized plates, one to a segment, known as tergites (fig. 13*b*), and ventrally by a similar set known as sternites (fig. 13, *s*). Toward the tip the sternites are modified in connection with the reproductive organs (fig. 14). The characteristic difference in size of the posterior-most few sternites affords an easy method for differentiating males from females. Those of the male are smaller (cf. *d* and *a*, fig. 14). Actually, the last one plainly seen in the female is the seventh, while in the male both the eighth and ninth are visible, although small. The sexes of soldiers and nymphs may be distinguished by the same characters.

Soldiers, while otherwise nymphal (immature) in that they lack the thick, pigmented exoskeleton of abdomen and thorax, and also the developed compound eyes, possess an enlarged and thickly chitinized head and greatly elongated and very heavily chitinized mandibles (fig. 69*c*).

CHAPTER 6

THE INTERNAL ANATOMY OF TERMITES AND THE HISTOLOGY OF THE DIGESTIVE TRACT

BY

HORACE J. CHILD

THE DIGESTIVE TRACT AND ASSOCIATED ORGANS

The digestive canal of *Zootermopsis* is one of the most interesting of its internal structures, for it is in this tube that the woody, relatively inert food of the insect is ground, strained, and subjected to the influence of enzymes which render it chemically useful to the animal. And it is here that the insect harbors a multitude of minute protozoan organisms, some of them indispensable to the host in the digestion of its own food material, others not indispensable, but living in apparent harmony with their host. The following description of the gut is based largely upon *Zootermopsis nevadensis*, especially upon the last nymphal instar of the reproductive caste of that species.

From the standpoint of embryonic origin, of structure, and of function, the gut is divisible into three well defined regions: the fore-intestine, the mid-intestine, and the hind-intestine. The first arises embryonically as an in-pushing of the anterior body wall, and is therefore designated as a stomodeum. It is lined throughout by a chitinous layer, or intima, which is continuous through the mouth with the chitinous exoskeleton. The intima of certain regions of the fore-intestine is developed into complex masticatory and food-straining structures, which will be described in greater detail in a later paragraph. The mid-intestine arises independently of the body wall, and thus lacks a chitinous lining. Its walls are glandular, and pour droplets of their secretion into the mid-gut cavity. These become mixed with the food mass and probably contribute enzymes to hasten digestion. The hind-intestine arises embryonically as an invagination of the body wall and is designated as a proctodeum. Therefore, like the fore-gut, it is lined with a chitinous intima, and this is continuous through the anal aperture with the exoskeleton. The liquid content of the hind-gut not only contains minute, partly digested wood chips, but furnishes the medium in which the myriad Protozoa live. In the fully formed insect these three regions of the intestine, of course, form a continuous tube, regionally specialized for the performance of various functions, but divisible into its embryonic constituents only on the basis of minute structure.

The fore-intestine.—Upon entering the mouth of a termite, food material finds itself in the forward region of the fore-gut, a region which is designated

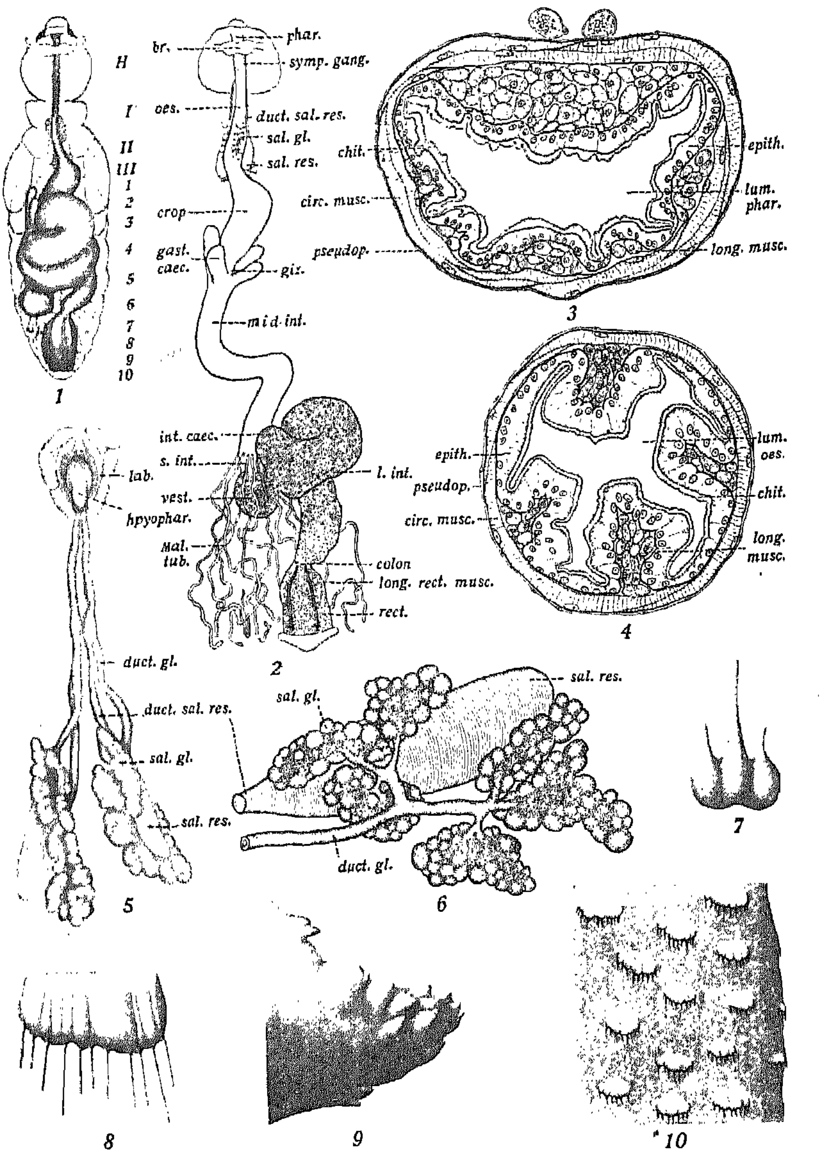

Fig. 15. The digestive system of *Zootermopsis nevadensis*.

(1). Dorsal aspect of gut and associated organs in normal positions in insect. × 5. *(2)*. Gut and associated organs removed from insect and uncoiled in dorsal view. Stippled portion shows region occupied chiefly by Protozoa; splashed portion, that occupied chiefly by undigested wood, forming fecal pellets in rectum. × 5.5. *(3)*. Cross section of pharynx showing tissue layers. × 304. *(4)*. Cross section of oesophagus showing tissue layers. × 304. *(5)*. Salivary glands, reservoirs, and ducts showing relation to mouth parts. × 16.5. *(6)*. Right salivary gland and reservoir somewhat spread out to show ducts. × 36.5. *(7)*. Chitinous denticle from surface of valvular cushion of gizzard. × 4000. *(8)*. Chitinous denticle from inner

as the pharynx (fig. 15 *(2)*). This is a minute tubular structure extending from the mouth back through the axis of the head cavity to the hinder part of the head, where it insensibly joins the oesophagus. Shortly posterior to the mouth it passes beneath the brain and through the ring of nerve tissue formed by the brain, the forward end of the ventral nerve cord, and the connectives between these. The dorsal surface of the pharyngeal tube is somewhat flattened, so that the transverse diameter is greater than the vertical dimension. From the walls of the pharynx delicate muscles extend dorsally, laterally and ventrally to the inner surface of the head capsule. Those visible in dorsal aspect are shown in figure 18 *(29)*. It is apparent that their contraction would dilate the pharynx and thus probably assist in the ingestion of food.

The wall of the pharynx (fig. 15 *(3)*) is extremely thin (0.018 to 0.065 mm. thick) and yet consists of five distinct layers of tissue besides the internal chitinous intima noted above. These are, in order, from the outside inward: (1) a delicate membranous layer which forms the outer surface of the tube and is known as a pseudoperitoneum; (2) a layer of muscle whose fibers extend circularly around the pharynx and whose contraction would therefore constrict the tube and oppose the action of the dilator muscles previously described; (3) longitudinal muscles, which are gathered together in six bundles; (4) a delicate network of connective tissue which binds the other tissues together; and (5) a layer of epithelium which secretes the inner, lifeless, chitinous intima. The intima, finally, presents on its inner surface an array of minute scale-like denticles. Each denticle is attached at its forward margin, and its free hinder margin possesses an armature of sharp spines. Since the scales and their spines point posteriorly, they must deter any forward movement of food and thus assist in ingestion and swallowing.

Of the six longitudinal muscle bundles the dorsal one is the largest. It bulges the epithelium and intima deeply into the cavity of the pharynx, as do the other five bundles to a lesser degree. The six longitudinal ridges thus formed on the inner aspect of the pharyngeal wall largely obliterate the cavity of the tube when the organ is at rest. But, as previously noted, the cavity may be enlarged by contraction of the dilator muscles and simultaneous relaxation of the circular muscles.

The oesophagus (fig. 15 *(2)*) is continuous with the hinder end of the pharynx. Beginning thus in the posterior part of the head it passes in the midline of the insect back to the central region of the thorax. Here it turns toward the right side of the animal and joins the crop. It is a slender, cylindri-

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surface of wall of crop. × 4000. *(9)*. Side view of one of twelve grinding teeth of gizzard. × 688. *(10)*. Portion of chitinous intima of crop showing arrangement of denticles. × 1305.

Abbreviations: *br*, brain; *chit*, chitinous intima; *circ musc*, circular muscle; *duct gl*, duct of salivary gland; *duct sal res*, duct of salivary reservoir; *epith*, epithelium; *gast caec*, gastric caecum; *giz*, gizzard, with proventricular dilator muscles above; *H*, head; *hypophar*, hypopharynx, or tongue; *int caec*, intestinal caecum; *l int*, large intestine; *lab*, labium; *long musc*, longitudinal muscle; *lum oes*, lumen of oesophagus; *lum phar*, lumen of pharynx; *long rect musc*, longitudinal rectal muscle bundle; *mid-int*, mid-intestine; *Mal tub*, Malpighian tubule; *oes*, oesophagus; *phar*, pharynx; *pseudop*, pseudoperitoneum; *rect*, rectum; *sal gl*, salivary gland; *s int*, small intestine; *sal res*, salivary reservoir; *symp gang*, ganglion of sympathetic nervous system; *vest*, vestibule; *I*, *II*, *III*, pro-, meso-, and metathorax; *1–10*, first to tenth abdominal segments.

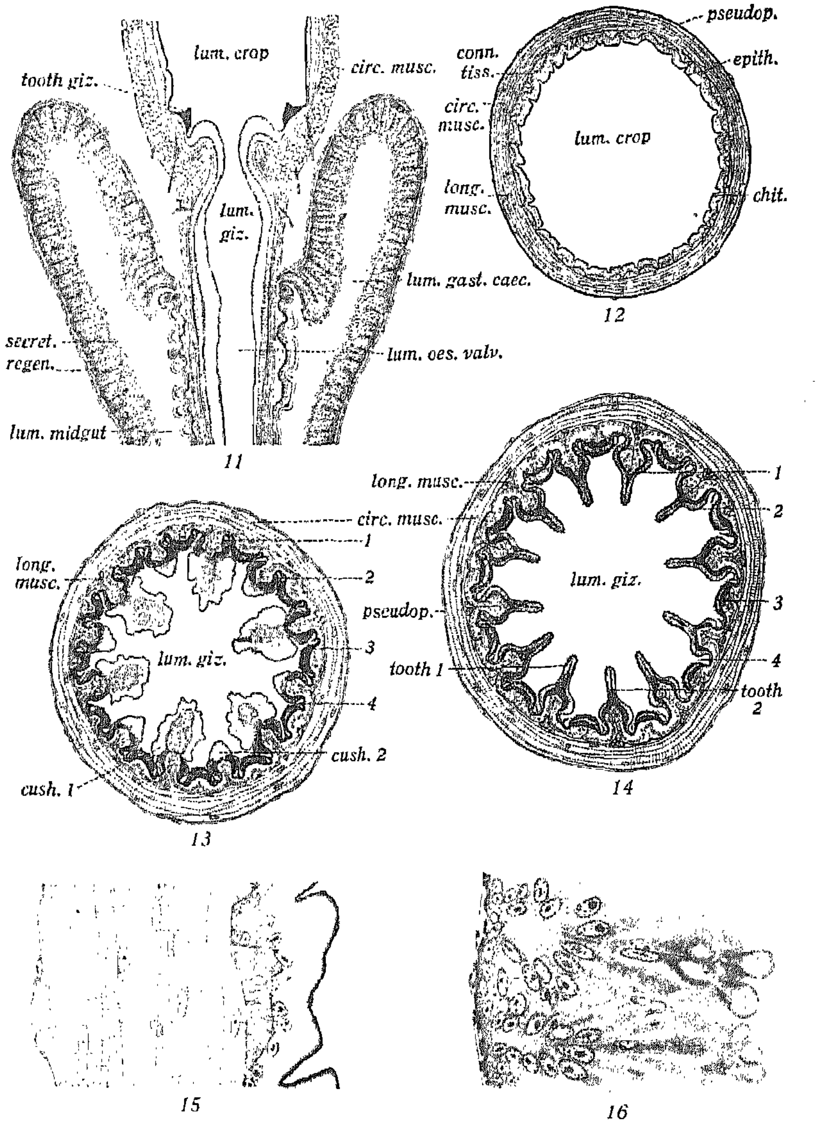

Fig. 16. The digestive system of *Zootermopsis nevadensis* (continued).

(11). Longitudinal section through gizzard, showing hinder end of crop, forward end of oesophageal valve and mid-intestine, and two gastric caeca. × 57. *(12)*. Cross section of crop showing tissue layers. × 57. *(13)*. Cross section of gizzard showing proventricular valve. × 108. *(14)*. Cross section of gizzard showing grinding and straining structures. × 108. *(15)*. Detail of crop wall. Note highly developed circular muscle. × 450. *(16)*. Detail of mid-gut wall. Note secretion droplets being extruded from epithelial cells and regenerative nest of epithelium. × 450.

Abbreviations: *chit*, chitinous intima; *circ musc*, circular muscle; *conn tiss*, connective tissue; *cush 1*, valvular cushion of primary ridge of gizzard; *cush 2*, cushion of secondary cal tube, of the diameter of the pharynx at its forward end, gradually widening throughout its course posteriorly until, as it joins the crop, it flares suddenly to the greater diameter of the latter. In a mature reproductive nymph it is about 3.5 mm. long.

The wall of the oesophagus (fig. 15 *(4)*) consists of the same tissue elements as compose that of the pharynx. The bundles of longitudinal muscle fibers are four in number in the forward end, and again six in number farther posteriorly. In any given region the sizes of the bundles are about equal. The epithelium and intima are so deeply folded over them that in the resting organ the longitudinal muscles are thrust inward and completely separated from the surrounding circular muscle layer. The ridges thus formed nearly obliterate the cavity of the organ.

In the passage of food, however, the circular muscles relax around the food mass, the wall is stretched out by pressure from within, and the ridges are obliterated. Since there are no dilator muscles to produce suction in any part of the oesophagus, movement of food in it must be accomplished by constriction of circular muscles in front of the food mass. A wave of such constriction would push the food toward the crop. Animals are occasionally dissected in which such a constriction was arrested by death. The oesophagus is apparently an organ for the swallowing of food. Forward movement of its content is deterred, as in the case of the pharynx, by an armature of denticles on the inner surface of its intima. Food is seldom found in any quantity in either the pharynx or oesophagus of dissected insects. It is probable therefore that the act of swallowing may be relatively rapid. In the crop, which succeeds the oesophagus, the food mass is apparently retained for a greater length of time.

The junction of the crop with the oesophagus lies in the hinder part of the thorax, and somewhat toward the right side of the animal (fig. 15 *(1)*, *(2)*). From here the crop extends obliquely toward the left, merging with the gizzard in the anterior region of the abdomen and at the left of the midline of the animal. It is a thick-walled, sack-like organ, about 2.7 mm. long. Its diameter depends upon the amount of its food content, but when distended its large forward end may reach a diameter of 1.1 mm. It is thus readily distinguishable from the smaller, tube-like oesophagus. Posteriorly it tapers gradually to the lesser diameter of the gizzard.

Although the crop wall (fig. 16 *(12)*, *(15)*) is made up of the same tissue layers as those which compose the wall of the pharynx and oesophagus, the arrangement and proportion of these layers are considerably altered in the crop. Here the circular muscle layer is enormously developed, so that it may constitute as much as two-thirds of the total thickness of the wall. The longitudinal muscle fibers are no longer gathered together in a few bundles, but are arranged in numerous groups of three or four fibers which form almost a

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ridge; *epith,* epithelium; *long musc,* longitudinal muscle; *lum crop,* lumen of crop; *lum gast caec,* lumen of gastric caecum; *lum giz,* lumen of gizzard; *lum midgut,* lumen of mid-gut; *lum oes valv,* lumen of oesophageal valve; *pseudop,* pseudoperitoneum; *regen,* regenerative nest of mid-gut epithelium; *secret,* secretion droplets of mid-gut; *tooth giz,* tooth of gizzard; *tooth 1,* tooth of primary ridge of gizzard; *tooth 2,* tooth of secondary ridge of gizzard; *1, 2, 3, 4,* ridges of first, second, third, and fourth orders, respectively.

continuous sheet of tissue inside the circular layer. The epithelium and intima are folded over these longitudinal fibers, but the thirty or more longitudinal ridges thus formed on the inner surface of the crop wall are low and flat-topped. Unlike the oesophagus, where the ridges largely filled the cavity, the crop thus has a capacious lumen. Finally, the chitinous layer lining this cavity is more heavily developed than in the pharynx and oesophagus, and its posteriorly directed denticles are more closely set and of heavier construction (fig. 15 *(8), (10)*).

As suggested above, the crop is usually filled with a closely packed mass of the woody food of the insect. This fact, together with the structure of the organ, indicates that the crop has a twofold function. First, it serves as a reservoir for the storage of swallowed food. Such storage is apparently necessary because of the slowness of the grinding process to which the food is subjected in the succeeding region of the gut. Second, by means of its heavy circular muscles, it compresses the food mass and keeps the latter pressed firmly against the grinding and straining structures of the gizzard. The chitinous denticles with their spines directed toward the gizzard must help insure movement of food in that direction rather than back into the oesophagus.

At its hinder end the crop merges with the gizzard (fig. 15 *(2)*). Externally the latter is an inconspicuous organ. It possesses the shape of a truncated cone about 0.5 mm. in diameter at its junction with the crop, and 0.2 to 0.3 mm. in diameter at its hinder end where the fore-gut is telescoped into the mid-gut. It is about 0.5 mm. long, and is normally quite hidden in the cup formed by four caeca or pouches which extend forward from the anterior end of the mid-intestine. From the wall of the gizzard, muscle fibers extend across the intervening space to the rim of the cup. These occur in four groups, corresponding to the four regions between the bases of the caeca, and are designated as proventricular dilator muscles.

The gizzard wall itself consists of the same tissue layers as have been described for the preceding regions of the fore-gut (fig. 16 *(11), (13), (14)*).

The circular muscle layer is heavily developed at the forward end of the organ, but dwindles away to an inconspicuous layer posteriorly. The longitudinal muscles present some modifications, which will be noted presently. The epithelium, and especially the internal chitinous intima, presents some remarkable modifications, forming grinding, straining, and valvular structures whose complexity is not paralleled in any other region of the gut. These structures may best be described as ridges of the inner surface of the gizzard wall, with regional specialization for the performance of the various functions suggested. There are forty-eight ridges, disposed longitudinally, and converging somewhat posteriorly with the convergence of the gizzard walls. They are of four types, and may be designated as ridges of the first, second, third, and fourth orders.

There are six each of the first- and second-order ridges, alternating with each other around the circumference of the gizzard. At their forward ends each of these twelve ridges presents a heavy chitinous tooth, which projects forward and into the gut cavity. Since they occur at about the same level, the twelve teeth form a circlet of masticatory structures whose cutting and crushing points and edges oppose each other (figs. 15 *(9)*; 16 *(11)*, *(14)*). Just behind the teeth, the ridges of the first order bulge deeply into the cavity of the gut, each forming a cushion-like projection which consists of well chitinized epithelium (fig. 16 *(11)*, *(13)*). Alternating with these six structures are six smaller cushions belonging to the second-order ridges. The twelve structures thus described, and especially those of the first-order ridges, form the so-called proventricular valve, which in a position of closure almost completely shuts off the entrance to the succeeding region of the gut. Each primary cushion is, however, provided internally with longitudinal muscles whose contraction would retract the cushion and open the valve. Behind the cushions the secondary ridges shortly dwindle away and disappear, while the primary ridges decrease somewhat in size but persist throughout the succeeding region of the gut.

Ridges of the third order are twelve in number, and occur between the primary and adjacent secondary ridges (fig. 16 *(13)*, *(14)*). Each presents a rounded, heavily chitinized surface to the gut cavity. These twelve structures lack teeth and cushions but possess stiff chitinous bristles which project into the lumen. The twenty-four fourth-order ridges occur between the tertiaries and adjacent primaries and secondaries. Each is a chitinous plate whose free edge extends into the gut cavity and is armed with bristles of chitin. Like the secondary ridges, those of the third and fourth orders occur in the forward part of the gizzard, and farther posteriorly dwindle in size and disappear.

The action of this complicated organ has not been observed, but may be inferred with considerable assurance from the structure and arrangement of the parts described. It will be recalled that the crop, which opens widely into the forward end of the gizzard, is normally filled with a compact food mass. This consists largely of coarse splinters or chips of wood, of such sizes as were bitten off by the mandibles, and swallowed. This food mass is pressed posteriorly by contraction of the circular muscles of the crop wall, but its passage posteriorly is prevented by the proventricular valve with its twelve cushion-like flaps. Closure of the valve is accomplished by contraction of the strong circular muscles around it. This brings the hinder portion of the food mass just to the level of the twelve primary and secondary teeth, whose function is apparently masticatory. Contraction of the circular muscles around them thrusts their sharply serrated edges into the food mass. Withdrawal of the teeth to their resting position is accomplished by relaxation of the circular muscles and pressure of the gut contents, aided perhaps by contraction of the proventricular dilator muscles. Repeated "chewing" movements of this sort gradually break up the coarse particles of wood in the hinder portion of the food mass. Any food particles which slip through the proventricular valve around the bases of its cushions must necessarily be small, for the spaces are small and the bristles of the ridges of the third and fourth orders serve as a strainer which would hold back anything but finely divided particles. At intervals the proventricular valve is opened by relaxation of the circular muscles around it and retraction of the cushions by contraction of the retractor muscles within them. This is possibly aided by the action of the proventricular dilator muscles, whose contraction would enlarge the gizzard, and give the retractors a firm anchor against which to pull. Opening of the valve permits the passage of the hinder, ground portion of the food mass. Pressure of the crop walls moves the mass and brings a new, unground portion into position for mastication. With closure of the valve this process is repeated.

Food which has passed through this gastric mill finds itself temporarily in the hindmost portion of the fore-gut. This is usually designated as the oesophageal valve (fig. 16 *(11)*), though the structure is widely removed from the oesophagus and its name is not very appropriate. It is a tubular structure inserted in the forward end of the mid-intestine and completely hidden from view externally. It may be thought of as double-walled. The inner wall is a direct posterior continuation of the typical tissue layers of the fore-gut. These extend into the cavity of the mid-gut to a distance of about 1.8 mm., and are then reflected anteriorly to form the outer wall. The outer wall, in turn, joins the tissues of the mid-gut at the forward end of the valve. The two walls thus form a tube about 0.3 mm. in diameter.

The minute structure of the walls of the valve presents few remarkable features. There is of course no pseudoperitoneum, since the organ is nowhere exposed to the body cavity. With the doubling of the wall the longitudinal muscle layer becomes double. But the circular muscle layers of the two walls, being brought together back to back, become indistinguishable. The connective tissue layer is strongly developed, as is the epithelium. A delicate chitinous intima lines the tube internally and covers it externally, but the usual spiny denticles are lacking. The epithelium and intima form six longitudinal ridges internally. These, as noted above, are continuations of the primary ridges of the gizzard. Externally the epithelium and intima are thrown into folds which run around the tube, apparently providing a mechanism for permitting the valve to lengthen.

The function of the organ is obviously to prevent forward flow of food material which has reached the mid-intestine. The tube is attached only at its forward end, and elsewhere hangs freely in the mid-gut cavity. Any pressure of mid-gut contents would tend to collapse the flexible walls of the valve, closing the passage forward into the gizzard and crop.

The salivary apparatus.—A pair of salivary glands lie closely applied to the sides of the oesophagus in the middle region of the thorax (fig. 15 *(1)*, *(2)*, *(5)*, *(6)*). Each gland is a minute structure about 1.5 mm. long and consists of two lobes, one located anteriorly and dorsally, the other posteriorly and ventrally (fig. 15 *(6)*). Each lobe in turn consists of three smaller divisions or lobules. The lobules have an irregular lumpy appearance, due to the arrangement of the secretory cells which compose them. The liquid secreted by these cells is conducted away through minute ducts which unite to form progressively larger tubes until finally from each gland a single large duct passes forward beneath the oesophagus to the head.

An elongate, sack-like salivary reservoir lies obliquely between the lobes of each gland, its enlarged and rounded posterior end protruding dorsally above the posterior lobe. The anterior end of each reservoir tapers to form a duct which passes forward parallel to the duct of the gland. Thus from the thoracic region four ducts proceed to the head: two gland ducts and two reservoir ducts. In the head, between the pharynx and the floor of the head capsule, the gland duct and reservoir duct of each side unite to form a single tube. From this region forward two ducts pass to the base of the hypopharynx, or "tongue," beneath which they empty, in close proximity with the mouth.

The reservoirs and their ducts are thin-walled and transparent. In dissections of insects they are usually found filled with a clear, colorless, mobile liquid. In *Zootermopsis* the nature and functions of this "saliva" have not been determined. Whether or not it contains digestive enzymes, it is reasonable to assume that it is used to moisten the food of the insect, and thus to facilitate swallowing. Since there is no direct connection between the glands which produce the secretion and the reservoirs in which it may be stored, it is interesting to note that the stored secretion must have passed forward along the gland ducts to the head and back along the reservoir ducts to the reservoirs. This suggests further that when the insect is not eating the openings beneath the hypopharynx may perhaps be closed. If this be the case, any secretion produced by the glands at such a time would have no recourse but to flow from the common ducts of the head back along the ducts to the reservoirs to be stored for future use. In this connection it should be noted that the reservoirs are not constantly filled, and appear in some dissections quite collapsed and devoid of contents (fig. 15 *(5)*, *sal. res.*).

The mid-intestine.—The mid-intestine of *Zootermopsis* (fig. 15 *(1)*, *(2)*) does not show the great regional specialization which characterizes the fore-intestine. It is a moderately thick-walled tube attaining a diameter somewhat exceeding 0.5 mm. and a length of 7 or 8 mm. in the last nymphal instar of the reproductive caste. Its junction with the fore-gut has already been noted. This occurs toward the left side of the forward region of the abdomen, and is marked externally by the presence of four thumb-shaped out-pushings of the mid-gut wall, known as enteric caeca (fig. 15 *(2)*, *gast. caec.*). The four caeca arise from a broad shoulder and extend obliquely forward, ending blindly at their rounded anterior ends. They are symmetrically distributed around the circumference of the gut, and, together with the shoulder which bears them, form a cup which largely obscures the gizzard. Their walls and cavities are continuous with those of the mid-gut proper (fig. 16 *(11)*). They will be referred to again in a subsequent paragraph.

From the bases of the enteric caeca the tubular mid-gut proper extends posteriorly and describes a broad curve, first to the right, then forward along the right side of the animal, then over to the left, and posteriorly again, dipping beneath its own anterior end and joining the hind-gut at the left side of the middle region of the abdomen. In this circuitous course it completely encircles a loop of the hind-gut, which will be described subsequently.

The wall of the mid-gut (fig. 16 *(16)*) consists, as in the fore-gut, of five layers of tissue, but the arrangement and proportion of these differ considerably from those described in the fore-gut. From the outside toward the inside of the wall these consist of (1) a delicate pseudoperitoneum; (2) a weakly developed layer of longitudinal muscle fibers; (3) a similarly delicate layer of circular muscle fibers; (4) a strong layer of connective tissue; and (5) an internal layer of epithelium which bounds the gut cavity and constitutes by far the greater part of the thickness of the wall. It may be noted in passing that the relative positions of the longitudinal and circular muscles are the reverse of the condition found in the fore-gut. Further, there is no collection of muscle fibers to form bundles or sheets, as in the fore-gut. Rather, the mid-gut musculature presents the appearance of a delicate, coarse-meshed fabric.

Beyond these features, the chief interest in the mid-gut wall lies in the structure and great secretory activity of the epithelial tissue (fig. 16 *(11)*, *(16)*). The cells of the epithelium are arranged in clusters or "nests." A nest is a regenerative unit, in which old cells destroyed in the secretory process are replaced by younger cells. Mutual pressure of such nests upon each other's sides gives them polygonal shapes which may be seen, with some magnification, through the external tissue layers of the gut.

The center of a nest is occupied by small, young cells which multiply rapidly by cell division. Farther toward the periphery of a nest the older cells begin to show some elongation. Resting on slender bases set upon the connective tissue layer, they gradually lift their inner ends toward the cavity of the gut. The erection of such a middle-aged cell is accomplished by its own growth, and by pressure of the youngest, rapidly multiplying cells in the center of the nest. The oldest cells occupy the extreme periphery of a nest. They stand quite erect, their slender bases perpendicular to the outer connective tissue layer, their enlarged, club-shaped inner ends forming the inner aspect of the mid-gut wall. The inner ends of these oldest cells bear masses of close-set, hair-like processes which extend into the gut cavity, and are known collectively as the striated lamina.

It is these oldest cells which produce the secretion of the mid-gut. Their substance contains droplets of the secretion, minute in the deeper parts of the cells, attaining considerable sizes in the ends of the cells nearest the gut cavity. Such droplets of secretion are liberated into the cavity by two methods. First, they may be pushed out through the membrane of the cell and sloughed off much as a soap bubble leaves a soap bubble pipe. Second, the inner end of the cell itself may be pinched off with its contained droplets. Subsequent degeneration of the pinched-off portion liberates the secretion. These processes ultimately destroy the oldest epithelial cells. They are sloughed off, replaced by younger ones, and the cycle of secretion, destruction, and replacement continues.

This cycle is complicated by a second series of events which must now be briefly described. It has been noted that upon passing the oesophageal valve the food of the insect finds itself in the cavity of the mid-gut. It is obvious therefore that the material whose secretion has just been described becomes mixed with the food mass in the lumen of the mid-intestine. But this mixture does not lie free in the lumen. For, following a cycle of secretory events, the mid-gut epithelium produces a delicate, lifeless membrane, which is liberated as a cylindrical, sack-like structure. Its origin is not entirely certain. Since its formation follows a period of active secretion, it encloses a quantity of secreted material. And since the oesophageal valve hangs freely in its forward end it receives the food which enters the mid-gut cavity. It is thus appropriately called the peritrophic membrane. Following its formation a new secretory cycle pours secretion droplets into the space between the epithelium and the peritrophic membrane; and, with passage of the old trophic mass into the succeeding region of the gut, a new membrane is formed to contain the new secretion and to receive new food from the fore-gut.

The precise function of the peritrophic membrane is not known. It is conceivably a mechanism for conserving the mid-gut secretion, and for making a compact trophic mass which would afford better contact between food and secretion. As would be expected from its delicacy, it does not long persist; and food which passes on to the hind-intestine lacks such a container.

Neither has the exact nature and function of the mid-gut secretion been determined. It is of course reasonable to assume that it is a digestive juice, containing enzymes to hasten the digestion of the woody food of the insect. This is a logical deduction from analogy with other insects, and from the fact that the mid-intestine is the only region of the termite's gut where any secretion is produced on such a scale.

The hind-intestine.—The hind-intestine (figs. 15 *(1)*, *(2)*; 17) is the most conspicuous portion of the entire gut. This is due to its great distention by the Protozoa which inhabit it throughout the greater part of its length, and to the pronounced looping and coiling it undergoes to permit the abdomen to accommodate its great bulk.

The junction of the mid-intestine with the hind-intestine has already been noted. From this junction posteriorly the hind-gut consists of six well defined regions: (1) a postventriculus or small intestine; (2) a vestibule; (3) a large intestine; (4) a capacious intestinal caecum given off from the forward end of the large intestine; (5) a short colon; and (6) a rectum.

The postventriculus (fig. 17 *(17)*, *(21)*) is marked off from the mid-intestine by a shallow external groove which encircles the gut, and by a circlet of ten excretory organs known as Malpighian tubules, whose forward ends are inserted into the intestine at this level. These tubules are extremely delicate structures possessing diameters of the order of only 0.1 mm. From their attachments to the gut they extend in general toward the hinder end of the insect (figs. 15 *(2)*; 17 *(21)*), but they twist and turn, forming an intricate snarl, especially around the hinder portions of the gut. The cylindrical wall of a tubule consists of a single layer of relatively enormous cells, invested by a delicate pseudoperitoneum, such as covers the gut. The large cells of the wall bulge so deeply into the tubule that they largely obliterate its lumen. The narrow, irregular cavities which do remain end blindly at the free, hinder ends of the tubules, and empty into the cavity of the postventriculus at their forward ends.

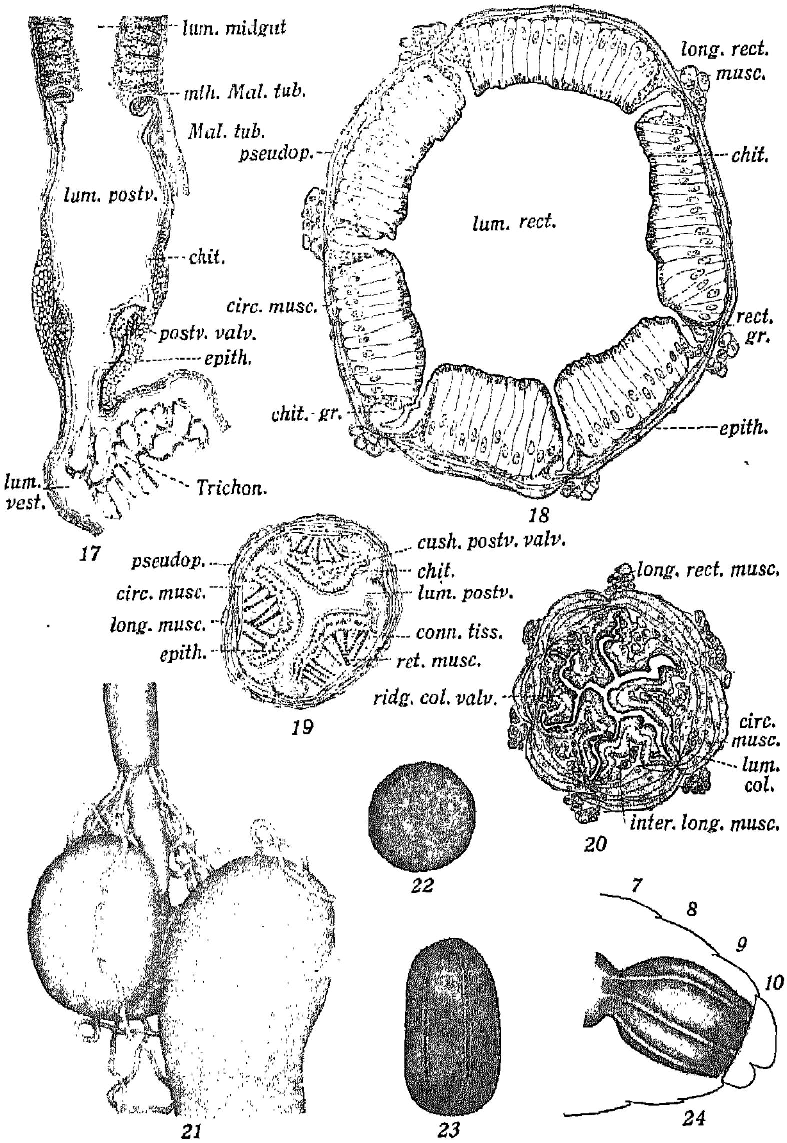

Fig. 17. The digestive system of *Zootermopsis nevadensis* (continued).

(17). Longitudinal section of postventricular region, including hinder end of mid-gut and forward portion of vestibule. × 60.7. *(18)*. Cross section of rectum. × 116. *(19)*. Cross section of postventriculus through valve. × 116. *(20)*. Cross section of colon through valve. × 116. *(21)*. Region of postventriculus, showing hinder portion of mid-gut, entrance of Malpighian tubules, vestibule, intestinal caecum and forward portion of large intestine. The specimen has been straightened to show structures normally hidden from above. × 16.5. *(22)*. Fecal pellet cut transversely to show outline. Compare with *(18)* and *(24)*. × 12. *(23)*. Fecal pellet seen from side. Compare with *(18)*, *(22)* and *(24)*.

The Malpighian tubules serve an excretory function. The space in which they lie surrounding the gut is filled with the colorless blood, or haemolymph, of the insect. Unlike the blood of many animals, this haemolymph is for the most part not confined to definite blood vessels, but flows through irregular spaces or sinuses, bathing the internal organs of the insect as it flows. Among its several functions it collects excretory materials from the tissues it bathes, and loses these in turn by their diffusion through the walls of the Malpighian tubes. From the cavities of the tubules they are emptied into the lumen of the postventriculus and are probably eliminated from the body in the fecal pellets, along with the undigested remnants of food materials.

The postventriculus proper is a short, narrow tube extending posteriorly from the hinder end of the mid-gut and the insertion of the Malpighian tubules. It is 1 mm. or less in length and tapers from an anterior diameter of about 0.5 mm. to half that size at its hinder end where it enters the vestibule.

The structure of the postventricular wall varies considerably at different levels (fig. 17 *(17)*). Its outer layer at all levels is the usual delicate pseudoperitoneum. Beneath this at the forward end there are well developed longitudinal muscle fibers. Inside these there is a thin sheet of circular muscle, a connective tissue layer, an epithelium, and finally, lining the cavity, a delicate chitinous intima. About midway between the two ends of the organ the wall becomes greatly thickened (fig. 17 *(17)*, *(19)*, *(21)*). The outer, longitudinal muscle fibers dwindle away, but the circular muscle layer becomes powerful and continues thus to the narrow opening of the postventriculus into the vestibule. The connective tissue and epithelium increase in thickness and bulge toward the lumen, forming three prominences (fig. 17 *(19)*). These alternate around the circumference of the gut with three smaller folds of the epithelium. In the three large prominences the musculature is somewhat altered. Its fibers are longitudinally or, in places, radially disposed, and their attachments are such that their contraction would retract the valvular prominences. The intima which covers the epithelium of these prominences presents a system of closely set denticles, each armed with a stout, sharp spike which is directed posteriorly.

The structures here described constitute the postventricular valve. Its construction and strategic position suggest a two-fold function. First, it controls the passage of food from the mid-gut to the succeeding regions of the hind-gut. Contraction of the powerful circular muscles constricts the gut wall, thrusting the valvular prominences deep into the lumen until they meet each other

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× 12. *(24)*. Colon and rectum seen from left side, in outline of hinder end of insect. × 7.5. *(7, 8, 9, 10*, seventh to tenth abdominal segments.)

Abbreviations: *chit*, chitinous intima; *chit gr*, chitinous intima of rectal groove; *circ musc*, circular muscle; *conn tiss*, connective tissue; *cush postv valv*, cushion of postventricular valve; *epith*, epithelium; *inter long musc*, internal layer of longitudinal muscle; *long musc*, longitudinal muscle; *long rect musc*, longitudinal rectal muscle bundle; *lum col*, lumen of colon; *lum midgut*, lumen of mid-gut; *lum postv*, lumen of postventriculus; *lum rect*, lumen of rectum; *lum vest*, lumen of vestibule; *Mal tub*, Malpighian tubule; *mth Mal tub*, mouth of Malpighian tubule; *postv valv*, postventricular valve; *pseudop*, pseudoperitoneum; *rect gr*, rectal groove; *ret musc*, retractor muscle of postventricular valve; *ridg col valv*, valvular ridge of colon; *Trichon*, *Trichonympha* in vestibule of hind-gut.

and completely block the passage. The relaxation of the circular muscles and contraction of the radial retractor muscles produce the opposite effect and permit the gut content to flow through the valve. Second, the valve serves as an effective check against back-flow of the contents of the vestibule. In this function the narrow posterior end of the small intestine would be the first line of defense. Beyond this, the valvular prominences would block the passage, and their armature of posteriorly directed spikes would be a further deterrent to solid particles and to Protozoa. In corroboration of this suggestion, it is interesting that the Protozoa, abundant in the succeeding vestibular cavity, are very rarely found in the small intestine anterior to the postventricular valve.

The vestibule (figs. 15 *(2)*; 17 *(17)*, *(21)*), which succeeds the postventriculus, is a relatively large, bulbous structure. When well distended it attains a diameter of almost a millimeter and is nearly spherical in shape. Its forward surface receives the hinder end of the postventriculus. Obliquely forward and to the right it communicates with the large intestine. The junction of the vestibule and large intestine is marked by a deep constriction. But succeeding the junction, the large intestine flares widely, so that, together with the broad intestinal caecum which projects forward from it, it forms a voluminous organ. From the region of the caecum the large intestine narrows, and ascends through the loop of the mid-gut. It describes a circle of its own to the right, then forward, and to the left, and descends again through the mid-gut circle. Beneath the mid-intestine it now turns posteriorly, describing a gentle curve toward the right side of the animal. Finally, it returns toward the midline and in the hinder region of the abdomen narrows to form the colon.

The extensive structure thus formed by the vestibule, the large intestine, and its caecum, constitutes the organ in which *Zootermopsis* harbors its multitude of protozoan laborers and guests. Histologically, the walls of these three regions are quite uniform, and show a nicety of adaptation to their living content. Such adaptation entails strength to withstand the considerable pressure of the voluminous content, and yet sufficient flexibility to permit total and regional fluctuations in volume.

The outermost, pseudoperitoneal layer is heavier than in most other regions of the gut, and appears to possess considerable strength. Within the pseudoperitoneum there are three muscular layers. The fibers of the outer layer are in general longitudinally disposed; those of the middle layer are circular; and those of the inner layer again longitudinal. The outer fibers are rather widely spaced; the middle and inner fibers are more numerous and closer together. The three layers form a basket-work of criss-cross fibers, capable of great constriction or of enormous distention. The epithelial tissue and chitinous intima appear to be equally flexible, though of course their changes in shape are entirely passive. In a gut which is highly distended these layers are stretched out to form a thin, smooth lining. In a gut whose content is small the muscle layers are contracted, and the epithelium and intima are thrown into deep folds which accommodate their substance but occupy a lesser area. Thus the walls of the organ at all times fit the content whether the latter is large or small, or whether it is temporarily massed in one region or another with shifting of the protozoan population.

The organ thus constituted contains a fluid mass consisting of (1) a quantity of watery liquid; (2) finely divided food material, chiefly wood chips, suspended in the liquid; (3) bacteria in great numbers and variety; and (4) enormous numbers of flagellate Protozoa actively swimming in the liquid. Ordinarily the Protozoa are in fact so numerous that they constitute by far the greater part of the content of the organ. Under these conditions the liquid forms merely a thin film between the bodies of the animals, leaving them what would seem to be scant room to manipulate their whip-like, locomotor flagella. They rub each other's sides; they twist and turn to avoid each other; by mutual pressure and by their own contractility they change their shapes and proportions to exist and move in their crowded quarters. The larger members of this protozoan population appear to live in a symbiotic relationship with their host. In return for food, protection, and a suitable medium in which to live, they render the termite a service which makes its own food available to it—a function which the termite is unable to perform alone.

It now becomes apparent that at least some portion of the voluminous organ formed by the vestibule, large intestine and caecum must serve a further function, that of absorption of the digested food material. This has not been demonstrated experimentally, but it is a logical conclusion from the fact that the insect's food is not completely digested until it reaches this region of the gut. And the conclusion is supported by the fact that this organ possess a greater surface for absorption than any other region of the intestine. Furthermore, its walls are thin, and their large external surface is bathed by the haemolymph whose flow would distribute the absorbed food materials to all parts of the insect's body.

As the large intestine passes posteriorly and narrows to join the colon, the character of its content becomes somewhat altered. The protozoan population becomes more sparse, and the gut cavity is filled largely with fragments of food material which have not yielded to the digestive action of enzymes either of the termite or of the symbiotic Protozoa. The last two organs of the digestive tract, the colon and rectum, are concerned, among other functions, with the elimination of this material from the body of the insect.

The colon (figs. 15 *(1)*, *(2)*; 17 *(24)*) is not an extensive organ. Externally it appears merely as a deep constriction between the large intestine and the rectum. Its wall is so constructed as to form a powerful valve between these two regions of the gut (fig. 17 *(20)*).

On its outer surface, beneath the usual pseudoperitoneum, the longitudinal muscle fibers are gathered together to form six strong muscle bundles. These are symmetrically spaced around the circumference of the gut, are longitudinally disposed, and extend beyond the colon along the surface of the rectum. The middle muscle layer, composed of circular fibers, is strongly developed, forming a powerful sphincter muscle. The inner longitudinal muscle fibers are grouped in six bundles so placed that they alternate with the six external bundles. Finally, the epithelium and the thick intima are thrown into six deep longitudinal folds, which practically fill the lumen of the organ. The six ridges correspond in position with the six internal muscle bundles; the six grooves between the ridges occur just beneath the six external muscle bundles.

The shape of any given fold is remarkably adapted to the contours of adjacent folds, so that, pressed together by contraction of the sphincter, they must completely close the cavity of the colon and prevent passage of material from large intestine to rectum. Opening of the valve may be accomplished by relaxation of the sphincter muscle and internal pressure of the content of the large intestine. A further function of the valvular colon will be suggested in connection with the behavior of the rectum.

The rectum (figs. 15 *(1)*, *(2)*; 17 *(24)*) is the hindmost division of the digestive tract. Just back of the colon it flares conspicuously and then narrows gradually as it approaches the anal aperture. Depending upon its content, it may attain a diameter of a millimeter or more, and a length of two or more millimeters. It thus forms an elongate, bulbous structure for temporary storage of undigested food particles, and for moulding of these into fecal pellets which are ultimately voided through the anus.

The wall of the rectum (fig. 17 *(18)*) consists of the same tissue layers as were described for the colon, but some of these become considerably modified in the rectal wall. The six external, longitudinal muscle bundles extend the length of the organ, giving it a heavily ribbed appearance. The insertion of these muscles in the wall of the colon has already been noted. At their hinder ends they are attached to the inner surface of the insect's exoskeleton; specifically, to the inner surface of the tergite and sternite of the tenth abdominal segment. Their hinder attachments thus form a circlet around the anal aperture.

The circular muscle layer of the rectal wall is strongly developed, but does not compare with the powerful sphincter of the colon except in the anal region, where it forms a sphincter which closes the anal aperture. The inner longitudinal muscles described in the large intestine and colon persist for a short distance in the forward end of the rectum, and then dwindle and disappear. In the anal region special radial muscle fibers extend from the gut wall to the body wall. Their contraction would dilate the gut in this region.

The epithelial layer of the rectum is enormously thickened, so that together with its heavy chitinous intima it constitutes from two-thirds to three-fourths of the entire thickness of the wall. Symmetrically around the circumference of the organ the thick epithelium is interrupted by six longitudinal grooves. These are lined with chitin supported by a more delicate epithelium, such as is found in the colon. Each groove corresponds in position with one of the six external longitudinal muscle bundles. Furthermore, each groove is continuous anteriorly with one of the grooves described in the colon, and thus ultimately communicates with the cavity of the large intestine. The six blocks of rectal epithelium thus separated by the rectal grooves are, then, modified continuations of the six parts of the valve of the colon.

In the colon these ridges possess convex surfaces which fit each other and may close the lumen of the organ. In the rectum, on the other hand, the epithelial ridges are broad, with flattened or actually concave surfaces. Thus, with their chitinous intima they line the spacious cylindroidal cavity of the rectum, giving it, in cross section, a roundly hexagonal outline.

In this cavity undigested food particles gradually accumulate, closely confined posteriorly by the sphincter ani, anteriorly by the sphincter coli, and circumferentially by the hexagonal walls of the rectum itself. Contraction of the circular rectal muscles and resulting pressure of the six internal chitinous surfaces now press these particles into a small pellet. The characteristic shape of a fecal pellet (fig. 17 *(23)*) is obviously determined by the conformation of the structures which mould it. A typical pellet is elongate, with rounded ends, and possesses six flattened or broadly rounded surfaces. At the angles between these surfaces occur six double longitudinal ridges separated by a shallow longitudinal groove. The six surfaces are obviously the result of pressure of the six plates of rectal epithelium. The six sets of ridges and grooves correspond in position with the six rectal grooves described above.

It is an interesting fact that whereas the content of the large intestine is highly liquid, the fecal pellet when ready for elimination is moist, but of a relatively solid consistency. This indicates that a further function of the rectum is to press out and conserve the water content of material which enters through the colon. This water may conceivably be absorbed through the rectal wall. The structure of the wall suggests that water may be pressed out as the pellet is moulded. Thus squeezed out of the fecal mass, it would collect in the longitudinal rectal grooves, and through them might flow forward into the large intestine again. Along each of the six angles of a pellet there is usually a row of light brown granules, suggesting that as the water leaves through the rectal groove there is strained out or otherwise deposited from it its suspended content of waste materials. Whatever the precise mechanism may be, this conservation of water must be an important factor in the life of the insect, whose water supply is not always abundant.

Elimination of the fully formed pellet is accomplished by relaxation of the anal sphincter, and contraction of the radial and longitudinal rectal muscles. Since the hinder end of the organ is anchored by the body wall, this contraction pulls the forward end of the rectum posteriorly. And, with the valvular colon closed, the pellet must be voided through the anal aperture.

Occasionally, upon being disturbed, a termite loses in addition to the rectal content a quantity of the content of the large intestine. Complete loss of protozoan fauna would be disadvantageous to the animal, and this is apparently prevented by the vestibule described in an earlier paragraph. In an animal opened immediately after such loss of intestinal content, the vestibule is usually found to have retained at least a considerable portion of its protozoan population. This retention is probably accomplished through complete closure of the already constricted region separating the vestibule and large intestine.

Changes in the gut accompanying the molt.—Heath (1927) and Heath and Wilbur (1927) have admirably described the characters of the various instars of *Zootermopsis,* and the anatomical changes which accompany the molting process. Andrew (1930) has made an excellent study of changes in the intestinal content attendant upon ecdysis. She states that about a month before the molt the intestine appears normal in every way, and possesses its usual content of food material and Protozoa. From three to four weeks before the molt the termite enters a period of self-starvation, so that the food content of the intestine disappears, but the Protozoa remain. However, with their food supply cut off, the wood-eating Protozoa gradually starve and disappear. Of these, the three species of *Trichonympha* (fig. 20*e–g*) go first, followed by *Trichomonas* (fig. 20*c*), so that all four are completely absent before the actual molt occurs. Of the other three species of Protozoa present *Streblomastix* (fig. 20*a*) may or may not remain through the period of the molt, and *Tricercomitus* and *Hexamastix* (fig. 20*b, d*) always persist in the intestine.

The changes in the intestine itself during ecdysis are of interest. It will be recalled that the fore- and hind-intestines are lined with chitinous intimae which are continuous through the mouth and anus, respectively, with the chitinous exoskeleton of the insect. It is not surprising, then, that with the shedding of the exoskeleton these chitinous linings are also shed.

Dissections of insects which have very recently molted disclose the old fore-gut intima shed and lying unattached in the fore-gut lumen. The shed intima includes in every detail the lining of every part of the fore-intestine, with its scale-like denticles and complicated grinding structures. But in such preparations a new intima has already been secreted by the epithelium, perfect in every detail, though at first somewhat more delicate than the old one. Contrary to what might be expected, the old fore-gut intima is not regurgitated, but is swallowed, and may be found in a tightly folded mass first in the oesophageal valve, and subsequently in the mid-intestine. As it moves posteriorly it appears to degenerate, and this fact suggests that the insect may digest it and utilize its food value. The suggestion is not unreasonable when it is recalled that termites normally eat the dead in their colonies, and that the chitinous portions of dead insects probably serve normally as part of the animals' diets.

The shedding and replacement of the hind-gut intima is similar to the process in the fore-intestine. The intima here is more delicate, and the cast-off old one forms a small wrinkled mass which moves posteriorly and is voided through the anus. Andrew states that it is eliminated on the second or third day after the molt, though it is possible that the material observed by her is that to be described in the next paragraph.

The mid-intestine possesses no chitinous lining, hence has none to lose during the molt. But with its digestive function temporarily suspended, it seizes the opportunity, as it were, to cast off its old, degenerate epithelial cells. These are shed in enormous numbers, so that they largely fill the mid-gut cavity. There is formed around them what appears to be an especially thick peritrophic membrane, and, thus enclosed, they move as a compact cylindrical mass down the digestive tract to be eliminated through the anus. As they move, they degenerate further, almost losing their identity before they are voided from the gut. Their places in the mid-gut wall are taken over by the next oldest epithelial cells. Thus, after the molt the fore- and hind-intestine possess new chitinous linings, and the mid-gut an essentially new epithelium.

Having thus renovated its digestive tube, the termite must re-acquire a protozoan fauna. As noted above, the three smaller, non-symbiotic species of Protozoa may remain in the gut throughout the molt. But the larger species, essential to the insect's digestive processes, must be re-acquired from other termites. The exact method of refaunation is not known. That a termite acquires its Protozoa by feeding upon material containing them is demonstrated by the work of Andrew, and by the fact that apparently normal Protozoa are occasionally found in the fore-gut as though in process of being swallowed. That the infective material is stomodeal, acquired from the mouths of fellow termites, is highly improbable, since the array of valves between the hind-gut and the mouth would effectively prevent passage of Protozoa forward through the gut. Andrew demonstrated that feces do not normally contain living Protozoa and are not a source for refaunation. She points out that a termite cannot refaunate itself by eating its own intestinal lining after ecdysis, since this was emptied of the symbiotic Protozoa by starvation before the molt. Three possibilities remain: transfer of fauna through cannibalistic feeding; transfer through feeding upon liquid droppings voided after defecation; and transfer through proctodeal feeding, *i. e.*, feeding upon liquid intestinal content taken from the anal aperture of a fellow termite. The third suggestion Andrew considers at least one of the normal methods of refaunation.

From whatever source they come, the Protozoa which reach the hind-intestine of their new host proceed to reproduce rapidly by fission. Andrew states that in the normal colony refaunation has usually taken place by the third or fourth day after the molt. Andrew and Light (1929) find that in *Zootermopsis* about three days after the molt the Protozoa present a "flare" of division, which shortly restores the normal population of the gut.

If the insect after ecdysis is still in a nymphal stage, normal feeding activities may shortly be resumed. If, however, the molt is the last in the development of the reproductive caste, and the resulting insect is the winged adult, the period of self-starvation is prolonged. Heath (1927) says, "During the remainder of its stay in the nest, no specimen has ever been seen in the act of feeding. Lightness of body evidently is of importance in the swarming period."

PERIPHERAL SENSE ORGANS

A termite's complex behavior is conditioned and determined in part by the insect's inherent organization, in part by stimuli which arise in the external environment. The peripheral sense organs are highly specialized structures for the reception of such stimuli and for their communication to the outermost parts of the nervous system. For this reason they are located at the surface of the body, especially in the case of the antennae and of those parts which most frequently come into contact with the sides of the burrows.

Noyes (1930) has made an excellent study of these organs as they occur in *Zootermopsis angusticollis.* The present section is based largely upon her work.

Noyes distinguishes three types of peripheral sense organs, and designates them as organs of Johnston, sensory pores, and sensory hairs. All three types agree in certain fundamental structural features. In each there is a minute ovoid or spindle-shaped sensillum which lies beneath the exoskeleton or cuticula of the insect. Inwardly a sensillum communicates with a nerve fiber which passes ultimately to the central nervous system. The sensilla thus appear as minute swellings at the outer terminations of the nerve fibers. From each sensillum a minute fiber known as a distal process extends outward toward or into the exoskeleton. Each distal process in turn ends in the outermost portion of the sense organ, a structure formed by interruption or modification of the cuticula. In the organs of Johnston this cuticular modification is not known; in the sensory pores it consists of a shallow depression; and in the sensory hairs it is a minute bristle (fig. 6*d, e*).

The organ of Johnston occurs only in the second segment of each antenna. Each organ consists of a group of sensilla arranged in a circlet around the circumference of the antenna. From the sensilla nerve fibers extend backward to the two branches of the antennal nerve which occupy the axial region of the segment, and distal processes extend forward to the wall between the second and third antennal segments. As noted above, the cuticular structures in which the distal processes terminate have not been seen. Nor is there a suggestion as to the particular type of stimuli received by the organ of Johnston. Noyes finds no difference in the organ as it occurs in the two sexes of *Zootermopsis,* but reports that the number of sensilla increases with the age of the insect.

Unlike the organs of Johnston, the sensory pores and hairs are widely distributed on various parts of the termite's body. Noyes distinguishes pores of three shapes: elliptical, almond shaped, and circular. At least the first two possess elevated margins. Each sensory pore is provided with a single sensillum and a process which extends from the latter to the center of the pore. Sensory pores may occur singly, or, more often, in groups. A group may contain pores all of the same shape, or of all three shapes noted above.

Sensory pores occur on the scapes of the antennae, on the clypeus near the attachment of the labrum or upper lip, and on all the mouth parts except the upper lip itself. On the legs they occur on the trochanter and tibia but not on the alternate coxa, femur, and tarsus. Careful experimental work is needed to establish the precise sorts of stimuli to which these receptors are sensitive. Their various locations suggest that they may serve different functions. Noyes makes two specific suggestions: that certain of the tibial pores, associated with spines of the same region, may serve as chemoreceptors; and that tibial pores located at the end of that organ nearest the body may possibly serve as chordotonal organs. The former, receiving chemical stimuli, would correspond most nearly to organs of taste and smell in the higher animals. The chordotonal organs would be receptors for vibrations. These might correspond to organs of hearing, sensitive to vibrations of the air; or, more probably in the termite, may be sensitive to vibrations transmitted through the wooden walls of the insect's burrows.

Sensory hairs vary in size and proportions from slender hair-like structures to stout bristles. Each arises from a minute cup-like depression in the chitinous cuticula of the insect. The hairs possess a delicate attachment in the floor of the cup, and from the region of this attachment a process extends inward to a sensillum. The latter in turn occurs at the end of a nerve fiber which extends ultimately to the central nervous system. On certain regions of the body, notably the legs, the sensory hairs are irregularly placed. On other parts they occur in definite circlets and rows, as on the cerci, the antennae, and certain of the mouth parts.

Sensory hairs occur on the scape and the flagellum of each antenna, and on all the mouth parts. They occur on all segments of the legs, especially on the outer surfaces, which most readily touch the objects of the insect's environment. Finally, the cerci and abdominal styles are well provided with sensory hairs.

Like the sensory pores, the hairs may serve to receive stimuli of various sorts. Many of them probably serve as organs of touch. A termite in locomotion carries its antennae directed forward, and actively moves them about over the surface to be traversed. Tactile hairs on these organs would then receive sensations of touch from the territory into which the insect is moving. Tactile hairs on the mouth parts would aid in the selection and ingestion of food particles. The legs extend out beyond the margins of the body, and tactile hairs on their outer surfaces would make contacts with the sides of the burrow. Finally, Noyes suggests a tactile function for the hairs of the styles and cerci, which extend beyond the posterior margin of the body and would receive contacts from behind.

Just behind the cutting edge of each mandible there is a heavy row of sensilla (fig. 6*e*) which cannot be classified as belonging to either pores or hairs. Noyes describes them as follows, and makes an interesting suggestion as to their possible function.

> Here the processes from the sensilla extend toward the surface of the cutting edge, but careful observation has failed to identify any specialized cuticular structures associated with their terminations. In extending the burrow through the wood *Zootermopsis* follows the more porous regions of the sapwood rather than the firmer heartwood. The terminations of the processes from the sensilla in the region near the cutting surface suggest that they may serve as organs of pressure for distinguishing differences in the regions of the wood to be excavated for the burrow.

A pair of compound eyes constitute special sense organs. They are located on the lateral surfaces of the head, behind the antennal sockets. They are innervated by short nerves which proceed very directly to the optic lobes of the brain. The eyes of *Zootermopsis* have not been studied in detail. Thompson (1922) and Heath (1927) have used them incidentally in studies of termite castes and development. They are of special interest because they do not attain full development except in the winged, adult insect. In the darkness of the wooden-walled burrows there can be little or no use for eyes. Young insects, normally confined in this darkness, possess inconspicuous, incompletely pigmented eyes. In the last nymphal instar of the reproductive caste the pigmentation increases. Heath says, "During the summer, for a brief period prior to the molting process which results in the winged insect, the eyes assume relatively large proportions, but dissections prove that in reality these organs belong to the next and last instar." With the final molt these become the functional eyes of the winged insect. They are large, and deeply pigmented. Correlated with these changes there is an increase in size of the optic lobes of the brain and of the optic nerves. Unlike the younger insects, the winged adults at the time of their flight are strongly attracted by light.

THE CENTRAL NERVOUS SYSTEM

The termite's receptors, or sense organs, which have just been considered are in a certain sense the outposts of the nervous system. It has been noted that each sense organ is associated with a nerve fiber. Many such fibers in a given region of the body join to form nerves which pass in turn to the central nervous system. Here impulses from all parts of the insect are coordinated, and from certain centers of the system impulses pass out along other fibers to muscles of the body, whose action they govern. These so-called motor fibers must in many instances proceed from the central nervous system in the same nerves which bring the sensory fibers to it, diverging from them as they near their destinations. The central nervous system is thus a mechanism for reception and coordination of impulses which arise in the sense organs, and for sending of impulses to the organs which effect the complex, coordinated movements of the body.

The central nervous system (fig. 19 *(34)*) consists primarily of a number of minute masses of nerve tissue arranged in a linear series from the forward region of the head to a point near the hinder end of the abdomen. Each such mass is known as a ganglion. Adjacent ganglia are connected by a pair of slender cords or connectives which lie side by side and close together. Ganglia and connectives thus present the appearance of a delicate chain. From the ganglionic portions of this chain nerves extend out to peripheral parts of the body.

The foremost and largest ganglion of the chain is designated as the brain (fig. 19 *(33)*, *(34)*). It is situated in the forward part of the head, its upper surface so closely applied to the dorsal wall of the head capsule that it may be seen in the living insect if the chitinous exoskeleton is not too heavily pigmented. It consists of two main lobes placed side by side and separated by a shallow median groove. Various swellings on the surfaces of these constitute smaller lobes. The whole organ fills nearly the entire width of the head capsule.

The optic lobes (fig. 19 *(33), opt. lobe*) are two prominent swellings, one on either side of the main mass of brain tissue. From them short, stout nerves extend to the compound eyes, which are located just adjacent to them in the wall of the head capsule. As noted in a previous section, the optic lobes and nerves attain their greatest size in the winged adult insect, in which the eyes are fully pigmented and functional. Just anterior to the optic lobes is a pair of smaller swellings, the antennary lobes (fig. 19 *(33), ant. lob.*). From each of these an antennary nerve extends into the adjacent antenna.

The ventral surface of the brain arches over the pharynx, and, with a transverse commissure beneath the pharyngeal tube, forms a complete ring of nerve tissue around the latter (fig. 19 *(33)*). From the forward surface of the brain, just beneath the pharynx, a pair of nerves arise and send branches to the labrum, or upper lip (fig. 19 *(33), nerv. labr.*).

From the ventral surface of the brain a pair of short, stout, parallel connectives (fig. 19 *(33), conn.*) extend ventrally to the second ganglion of the series. This is designated as the subpharyngeal ganglion *(sub-ph. gang.)*. Like it, all subsequent ganglia are located beneath the digestive tube, forming a chain along the midline of the floor of the body cavity. Three pairs of important nerves arise from the subpharyngeal ganglion. These extend forward to the mandibles, maxillae, and labium, respectively. Thus the sense organs and muscles of the head, antennae, and mouth parts are innervated by six pairs of nerves, three pairs proceeding directly from the brain, and three from the ganglion most closely associated with the brain.

Next in the series are three thoracic ganglia, occurring successively in the pro-, meso-, and metathorax (fig. 19 *(34), gang. I, II, III*). A pair of long, slender connections lying deep in the head and prothoracic cavities connect the subpharyngeal and prothoracic ganglia. The three thoracic ganglia communicate with each other through short, paired connectives. From each of the thoracic ganglia three pairs of important nerves arise. The anterior pair extend forward and somewhat laterally, diverging from the connectives in their forward course. In the prothorax these nerves are small, and terminate in many minute branches which apparently innervate certain muscles of the prothoracic floor. In the mesothorax and metathorax they are well developed and are the principal nerve supply of the wing muscles (fig. 19 *(34), nerv. wing*). They are especially conspicuous in the winged insect, in which the wing muscles are enormously developed. The second pair of nerves from each thoracic ganglion are conspicuous in all instars studied. They extend laterally and somewhat forward. Their numerous branches are distributed to the thoracic muscles and walls. The third pair of nerves arise from the hinder margins of each ganglion. Each divides immediately, sending a small branch laterally into the thorax itself, and a second, very large nerve posteriorly and ventrally into the adjacent leg. Since they are the only nerves to the legs, they must constitute the nerve supply of both the sense organs and muscles of the legs (fig. 19 *(34), nerv. leg*).

The thoracic ganglia and their connectives and lateral nerves lie deeply hidden beneath the complex musculature of the floor of the thorax. They are disclosed from above only after careful dissection of these muscles. As the ventral nerve chain emerges from the thorax and passes into the abdomen it lies free on the floor of the abdomen, unobscured by other structures once the gut and fat body have been removed. There are six abdominal ganglia, lying in the second to seventh abdominal segments. They are connected by slender, paired, longitudinal cords. The first five abdominal ganglia are small. Each gives off two pairs of delicate lateral nerves which follow the floor of the abdomen and shortly become lost from view beneath the ventral sheet of muscles. The sixth abdominal ganglion is decidedly larger than the preceding five. It lies in the seventh segment of the abdomen and gives off four pairs of nerves. The first two pairs of these innervate the structures of the seventh segment and appear very much like the nerves of the preceding five ganglia. The third pair proceed posteriorly and constitute the nerve supply of the eighth segment. The nerves of the fourth pair are distinctly larger than the preceding ones. They extend posteriorly and branch conspicuously, innervating the ninth and tenth abdominal segments. Branches extend to the wall and muscles of the ninth segment, to the reproductive organs, to the anal region, anal cerci, and to the genital appendices or styles of the male insect. Although the nerves of the abdominal ganglia are not conspicuous, they serve, among other functions, to activate the muscles by which respiratory movements of the insect are accomplished. In certain other insects there is evidence that each abdominal ganglion is a nerve center for control of respiratory movements of its own segment.

The functions of the digestive tract and other internal organs are governed by the so-called sympathetic nervous system. This consists of an intricate network of extremely delicate nerves which communicate at numerous points with the central nervous system, and ramify widely to parts of the gut and other viscera. The sympathetic system of *Zootermopsis* has not been studied in detail. A pair of sympathetic ganglia associated with the pharynx is shown in figure 15 *(2) (symp. gang.)*.

THE MUSCULAR SYSTEM

The skeletal system of the termite is to be found chiefly on the outside of the body. An exception is the chitinous tentorium in the head, but for the most part the rigid structures against which the muscles pull are parts of the exoskeleton. Most of the skeletal muscles are thus more or less peripherally located, and are attached to the inner surface of the cuticula, parts of which they use for levers to accomplish the complex movements of the body. Nelson (MS) has made a study of some of the more important skeletal muscles in *Zootermopsis angusticollis*. The present account is based largely upon her work, and the writer acknowledges use of a plate from her excellent drawings.

The abdominal muscles are relatively simple in arrangement, and will be considered first. The principal muscles of the abdomen may for convenience be classed as longitudinal and dorso-ventral. The longitudinal muscles are further divisible into sternal and tergal muscles. The sternal muscles form a sheet which covers almost the entire floor of the abdominal cavity (fig. 18 *(25)*, being interrupted only down the midline by the ventral chain of ganglia of the central nervous system. The sternal muscle fibers are longitudinally disposed. They arise from a given sternite near its forward margin and extend back to their insertion in the corresponding region of the segment behind. The tergal muscles (fig. 18 *(27)*) are similarly arranged, but their fibers are more widely spaced and do not form continuous sheets. The longitudinal sternal and tergal muscles are retractors of the abdomen. Their simultaneous contraction would shorten the abdomen. Contraction of the sternal or tergal muscles alone would bend the abdomen down or up, respectively.

The dorso-ventral muscles are situated in the lateral regions of each abdominal segment. As their name implies, they extend vertically, connecting the lateral edges of the sternites with corresponding parts of the tergites above (fig. 18 *(26)*). Contraction of these muscles compresses the abdomen in its vertical dimension, and probably constitutes the chief means by which the termite drives air out of the abdominal tracheae, or air tubes. Relaxation of the muscles involved in exhalation would permit the body wall and tracheae, of their own elasticity, to resume their former shapes. This would draw air into the tracheal tubes. These movements repeated at intervals constitute the breathing movements of the insect.

These movements may be assisted by the broad alary muscles (fig. 18 *(27)*), which are attached by narrow ligaments laterally between abdominal tergites and extend fan-shape to the midline, where they join their fellows of the opposite side; and by small pleural muscles which are attached to the forward edges of the abdominal pleura and extend to the centers of preceding pleura. Finally, it may be recalled that certain muscles of the gut are attached to the exoskeleton of the last abdominal segment. These are the longitudinal rectal muscles and the dilator muscles of the anal region, mentioned in an earlier section as being concerned in the process of defecation.

In the thorax the musculature is considerably heavier and more complex than in the abdomen. For besides movement of the thorax proper, the thoracic muscles are concerned with movements of the legs, and, in winged insects, of the wings. Only the more important features of the thoracic musculature will be considered.

On either side of the floor of the thorax there is a band of longitudinal sternal muscles (fig. 18 *(25)*). At their hinder end they form a broad sheet which extends over into the abdomen, becoming attached at the junction of the first and second abdominal sternites. In their forward course they become narrower, extending finally as stout narrow bands into the hinder part of the head. Their course is complicated by numerous attachments, and by fibers which extend obliquely from their course to the center and sides of the thoracic floor. Figure 18 *(25)* gives an idea of this complexity. The longitudinal tergal muscles of the thorax (fig. 18 *(27)*) include two stout bands, one on either side of the dorsal midline. These are interrupted segmentally, possessing attachments similar to those of the tergal muscles of the abdomen. The sternal and tergal muscles of the thorax and abdomen are concerned with movements of the thoracic segments in relation to each other, and with movements of the head and abdomen in relation to the thorax.

The most conspicuous muscles of the thorax extend in a dorso-ventral direction and are concerned with the movements of the legs, and of the wings when the latter are present. From the origin of each leg in the floor of the

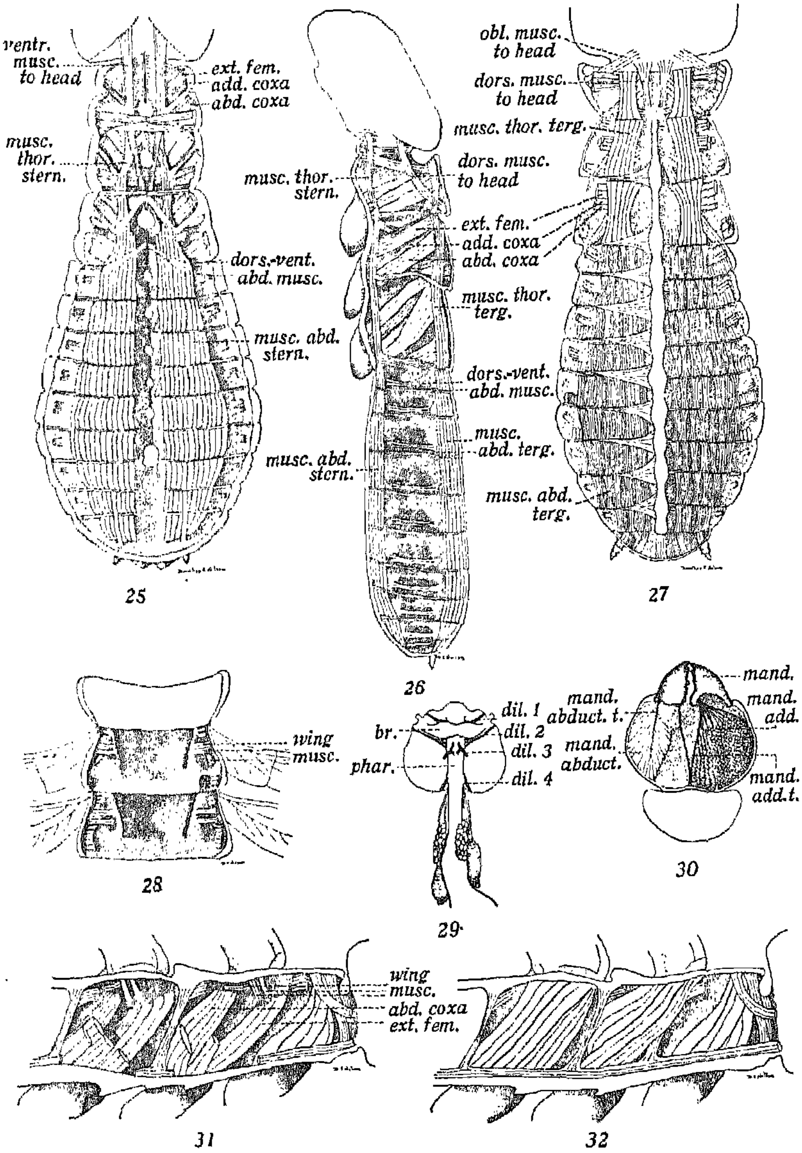

Fig. 18. Muscles of *Zootermopsis*. [Nos. *(25)–(28)*, *(31)* and *(32)* of *Z. angusticollis*, by Dorothea E. Nelson; Nos. *(29)* and *(30)* of *Z. nevadensis*.]

(25). Muscles of ventral wall of nymphal insect. × 6.6. *(26)*. Muscles of right lateral wall of nymph. × 6.6. *(27)*. Muscles of dorsal wall of nymph. × 6.6. *(28)*. Dorsal wall of adult insect showing wing muscles. × 6.6. *(29)*. Head of nymph showing dorsal pharyngeal dilator muscles. × 6.5. *(30)*. Head of nymph showing mandibular muscles. The right adductor covers the right abductor. The left adductor has been removed to disclose the abductor. × 7.6. *(31)*. Left lateral wall of adult insect dissected to show wing muscles.

thorax three powerful muscles extend upward and obliquely forward to the anterior and lateral region of the tergite above. The foremost of these is the external femoral which extends from the femur through the coxa to its tergal attachment (fig. 18 *(25), (26), (27), (31), ext fem.*). The other two are the adductor and abductor of the coxa. These extend from the inner surface of the coxa to their tergal attachments. These three muscles produce extensions and flexions of the proximal portions of the leg. The muscles of the more distal portions of the legs have not been studied in *Zootermopsis.*

In the winged adult the dorso-ventral muscles of the thorax become enormously developed and constitute by far the greater part of the entire thoracic content (fig. 18 *(31), (32)*). They crowd and largely obscure the thoracic digestive apparatus which is, as noted above, temporarily not concerned with its digestive function. According to Nelson, the leg muscles just described probably aid the wing movements. This they would do by depression and elevation of the meso- and metathoracic tergites to which the bases of the wings are attached. In addition to these, three true wing muscles are associated with the origin of each wing. Each of the three is attached at one end to the base of the wing. One extends posteriorly and attaches at its other end to the tergite; the other two extend ventrally and become attached to the tergal wall. These muscles are represented in figure 18 *(28), (31) (wing musc.).*

The muscles of the head are concerned chiefly with movements of the head upon its articulation with the prothorax, and with movements of the mouth parts. Of those which move the head, two have already been noted. These are continuations of the longitudinal sternal muscles of the thorax (fig. 18 *(25), (26)*). Their forward attachment is within the head capsule, and their contraction would bend the head downward. Elevation of the head is accomplished by two muscles which occupy corresponding positions in the dorsal region of the animal (fig. 18 *(26), (27)*). These originate in the middle region of the prothoracic tergite, and extend forward to their insertions on the hinder margin of the dorsal wall of the head capsule. Finally, there are two muscles which turn the head to one side or the other. These are inserted near the elevator muscles just described, but extend obliquely into the thorax to their origins on the lateral margins of the prothoracic tergite (fig. 18 *(27)*). Since these latter are located dorsally, they may by simultaneous contraction assist in lifting the head. But contraction of one with simultaneous relaxation of the other would turn the head toward the side of the contracting muscle.

× 8.3. *(32).* Muscles of left lateral wall of adult insect. Note great development of leg muscles, which probably also aid in flight. × 8.3.

Abbreviations: *abd coxa,* abductor muscle of coxa; *add coxa,* adductor muscle of coxa; *dil 1–dil 4,* pharyngeal dilator muscles; *dors musc to head,* dorsal muscle from prothorax to head; *dors-vent abd musc,* dorso-ventral muscles of abdomen; *ext fem,* external femoral muscle; *mand,* mandible; *mand abduct,* abductor muscle of mandible; *mand abduct t,* tendon of mandibular abductor; *mand add,* adductor muscle of mandible; *mand add t,* tendon of mandibular adductor; *musc abd stern,* longitudinal sternal muscle of abdomen; *musc thor stern,* longitudinal sternal muscle of thorax; *musc abd terg,* longitudinal tergal muscle of abdomen; *musc thor terg,* longitudinal tergal muscle of thorax; *obl musc to head,* oblique muscle from prothorax to head; *phar,* pharynx; *ventr musc to head,* ventral muscle from prothorax to head; *wing musc,* wing muscle.

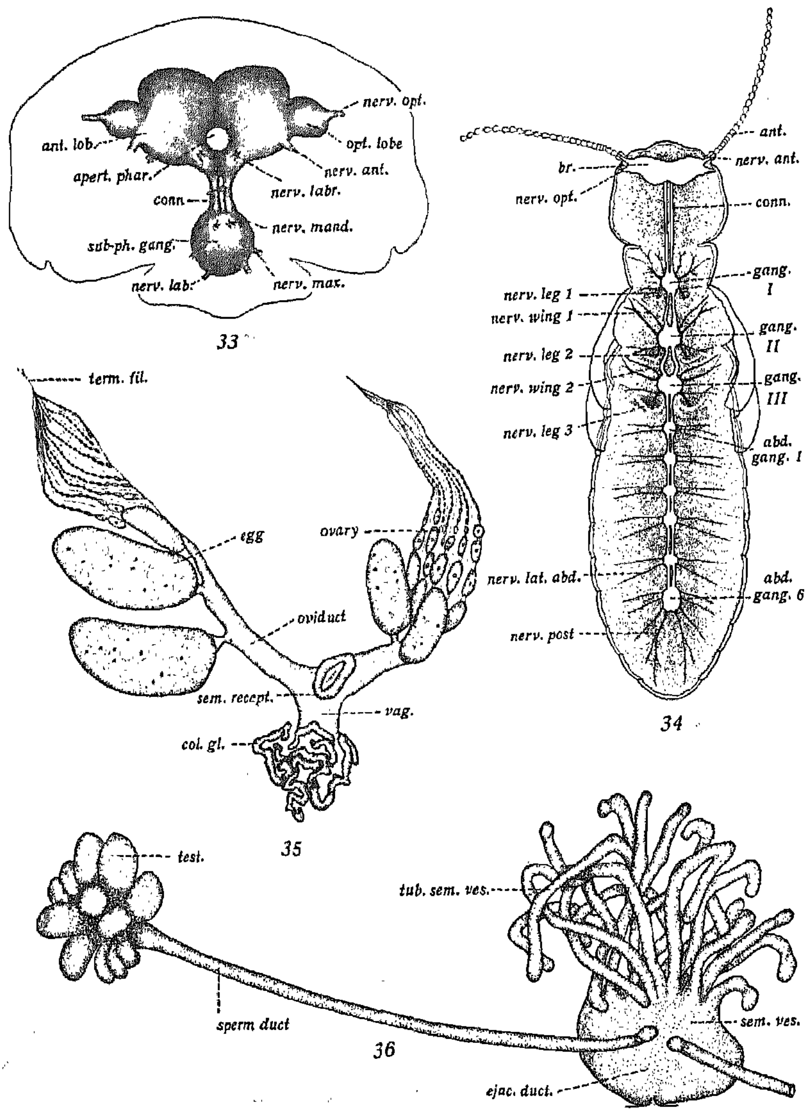

Fig. 19. The nervous and reproductive systems of *Zootermopsis*.

(33). Brain and subpharyngeal ganglion of *Zootermopsis nevadensis* seen from front. *(34)*. Central nervous system of *Zootermopsis nevadensis* seen from above. × 8.3. *(35)*. Reproductive system of adult female of *Zootermopsis angusticollis*. Redrawn from Thompson. × 54. *(36)*. Reproductive system of adult male of *Zootermopsis angusticollis*. The right testis and sperm duct are omitted. Redrawn from Thompson. × 54.

Abbreviations: *adb gang 1*, *abd gang 6*, first and sixth abdominal ganglia; *ant*, antenna; *ant lob*, antennary lobe of brain; *apert phar*, aperture for pharynx, which has been removed in dissection; *br*, brain; *col gl*, collaterial gland; *conn*, connective between ganglia; *egg*, nearly mature egg in ovary; *ejac duct*, ejaculatory duct; *gang I*, *gang II*, *gang III*, ganglia of pro-, meso-, and metathorax; *nerv ant*, antennary nerve; *nerv lab*, nerve to labium; *nerv labr*, nerve to labrum and frontal ganglion; *nerv lat abd*, lateral

The muscles which move the mouth parts fill by far the greater part of the head capsule. Of the several such muscles, the four which operate the mandibles are the most conspicuous and interesting, and discussion will be limited to them. From the base of the inner, toothed margin of each mandible a chitinous tendon extends posteriorly beneath the brain, curves somewhat toward the midline and lies along the side of the pharynx (fig. 18 *(30), mand. add. t.*). From this tendon large muscle fibers extend upward to the roof of the head capsule, and posteriorly and laterally to the rear and side walls of the head. As the head is opened from above the muscle masses thus associated with the two mandibles constitute the chief structures visible, aside from the brain. They are the adductor muscles of the mandibles *(mand. add.)*. Their contractions pull on their respective tendons, which in turn pull the inner margins of the mandibles posteriorly. This swings the mandibles on their articulations with the head capsule, and brings their sharp cutting edges together. The abductor muscles *(mand. abduct.)*, which extend or open the mandibles, are much less strongly developed. This is to be expected, since it is the adductors whose force must be expended against the material being chewed, and the abductors must only open the mandibles to prepare them for another effective stroke. The mandibular abductors lie beneath the adductors, and from above are completely hidden by the latter. Their fibers arise from the sides, rear, and floor of the head capsule, and extend in general in a forward direction. The fibers on each side of the head become attached to a slender tendon *(mand. abduct. t.)*, which in turn extends forward to its attachment on the convex outer margin of the mandible, near the hinge on which the latter moves. Beneath the mandibular muscles lie the muscles of the ventral mouth parts. These have not been studied in detail.

THE REPRODUCTIVE SYSTEM

Heath (1927) states that the sexes of *Zootermopsis* are distinguishable at the time the young insects hatch. At this time the egg tubes of newly hatched females are in sharp contrast to the cylindrical testes of the males. The history of the reproductive organs is one of gradual development throughout the younger instars, and culminates in the conspicuous, functional gonads and accessory organs of the adult insects. Thompson (1922) has made a brief study of the reproductive organs of *Zootermopsis angusticollis*. The present account is confined largely to the organs of adult insects, and is based chiefly upon the studies of Thompson.

Among adult termites the sexes are readily distinguishable, for the male possesses, on the ninth abdominal sternite, a pair of short styles, or genital

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abdominal nerve; *nerv leg 1, nerv leg 2, nerv leg 3*, nerves to pro-, meso-, and metathoracic legs, respectively; *nerv mand*, nerve to mandible; *nerv max*, nerve to maxilla; *nerv opt*, optic nerve; *nerv post*, nerve to posterior abdominal segments; *nerv wing 1, nerv wing 2*, nerves to meso- and metathoracic wings; *opt lobe*, optic lobe of brain; *ovary*, consisting of egg tubes filled with eggs in various stages of maturity; *oviduct*, receiving the egg tubes; *sem recept*, seminal receptacle; *sem ves*, seminal vesicle; *sub-ph gang*, subpharyngeal ganglion; *term fil*, terminal filament of ovary which has been broken in dissection; *test*, testis; *tub sem ves*, tubules of seminal vesicles; *vag*, vagina.

appendices. The female lacks these styles. In the female, furthermore, the seventh abdominal sternite is very broad, and completely covers the eighth. Finally, in older females of the adult instar the abdomen is greatly distended with eggs, and this enlargement presents considerable contrast with the abdomen of the male.

In the female the ovaries (fig. 19 *(35)*) are large, elongate organs lying in the abdomen above, and at the sides of, the coiled gut. Each ovary consists of a large number of egg tubes or ovarioles which extend in an antero-posterior direction, and are bound together by connective tissue. The ovarioles contain eggs in all degrees of maturity. The minute, immature egg cells occupy the forward ends of the tubes, and the larger, more mature eggs occur in progressively more posterior parts of the ovary. Hence an ovary is swollen at its hinder end, and tapers anteriorly to a slender organ which terminates in a delicate thread, or filament (fig. 19 *(35), term. fil.*). The terminal filaments of the paired ovaries join each other and are attached in the thoracic region of the body. In the figure this attachment has been broken, and the ovaries are separated.

At their posterior ends the egg tubes of each ovary enter a larger tube, known as an oviduct. In the hinder part of the abdomen the two oviducts pass on either side of the coiled gut, around to the ventral abdominal region. Here they unite in a single vaginal duct *(vag.)* which opens to the outside of the animal beneath the seventh sternite. Associated with the vaginal duct is a seminal receptacle *(sem. recept.)*; and lying in the ninth and tenth abdominal segments is a collaterial gland *(col. gl.)*, which consists of a voluminous snarl of glandular tubules. These communicate with the vagina.

In the forward ends of the ovarioles primitive egg cells multiply rapidly by division. The older cells move down the egg tubes, maturing, accumulating yolk material, and growing as they go. Mature eggs, ready to be laid, pass down the oviducts and out the vaginal duct. The seminal receptacle serves as a reservoir for storage of sperm received in copulation. Before being laid, the eggs are fertilized by spermatozoa liberated from this receptacle. Thompson reports that in a mature female the tubules of the collaterial gland are thick, dilated, and filled with a fluid secretion. The function of this secretion, however, is not known.

When laid, the egg is elongate, slender, and, according to Thompson, slightly larger at the future head end of the insect which is to develop from it. Heath finds that freshly laid eggs of *Zootermopsis nevadensis* average 1.404 mm. in length, while those of *Z. angusticollis average* 1.6 mm. In eggs which are about to hatch these dimensions have increased considerably.

In the male termite, the spermatozoa arise in a pair of lobed testes (fig. 19 *(36), test.*). Compared with the ovaries of the female, the testes are inconspicuous organs. They are located, one on either side of the body, in the hinder region of the abdomen. As suggested above, each consists of a number of elongate, bulbous lobes, arranged in a cluster, and emptying at their central ends into a sperm duct, or vas deferens. The sperm ducts of the two testes pass ventrally at the sides of the body, and, beneath the coils of the intestine, pass along the floor of the abdomen to the midline, where they enter a pair of seminal vesicles *(sem. ves.)*. Above this junction the seminal vesicles consist of many small, convoluted tubules *(tub. sem. ves.)*. Ventrally, the seminal vesicles enter a short ejaculatory duct which terminates in a muscular penis. Through the latter the reproductive organs of the male open to the outside of the insect, at the hinder margin of the ninth abdominal sternite, between the bases of the genital styles.

In sections of the testes, the youngest sex cells are found in the outer, rounded ends of the lobes. Progressively toward the center of the testis are found cells in advancing stages of maturity. Mature spermatozoa found in the central space of the organ pass down the sperm duct. The tubular portions of the seminal vesicles appear to be glandular, and may contribute their liquid secretion to the seminal fluid which forms the medium for spermatozoa when the latter are ready for transfer to the female.

Unlike bees, termites do not mate during their flight. Copulation occurs after establishment of the royal pair in their new quarters. Furthermore, one mating does not furnish spermatozoa for all the eggs the queen may lay during the period of her reproductive activity, and copulation is repeated at intervals during the remainder of the lives of the royal pair.

CHAPTER 7

PROTOZOA IN TERMITES

BY

HAROLD KIRBY, JR.

In many termites there are populous assemblages of microscopic organisms, both animal and plant. The fluid contents of the hind intestine of a wood-eating termite will be found upon examination under the microscope to be a seething mass of active Protozoa, spirochaetes, and bacteria. In the region of the gut inhabited by the microorganisms there generally are few particles of wood that are not enclosed in the bodies of the Protozoa. Not all of these animals are xylophagous, however. Some species do not ingest solid food, but absorb dissolved organic nutrient material. A number obtain part or all of their nutriment by devouring other microorganisms.

The four classes of Protozoa, Mastigophora, Sarcodina, Sporozoa, and Infusoria, are all represented in termites of California. Almost all of the forms, however, are flagellates, belonging to the class Mastigophora. Of the Sarcodina, amoebae (fig. 23*i*) are present in a few termites, but in none of those in which the complex flagellates occur. The class Sporozoa is represented chiefly by gregarines (figs. 20*h*; 22*n*), which are sometimes found in *Zootermopsis* and *Reticulitermes*, but, unlike the flagellates, are absent from the termites of many colonies. A tissue-dwelling sporozoan (fig. 23*j*) was observed in one of hundreds of individuals of *Amitermes* that were examined. Of Infusoria there is one ciliate genus, *Nyctotherus* (fig. 23*h*), which occurs not infrequently in *Amitermes*.

The Protozoa in termites invite attention to several topics worthy of investigation. First, there is the matter of their morphology and life history, which is of unusual interest because of the variety and complexity of form and structure. In connection with the life histories of the Protozoa, their transmission from host to host must be considered. Secondly, there is the question of the evolution and distribution of the Protozoa. This is a subject of special importance to the student of host-parasite relationships because many of the flagellates belong to an order, and most of them to families or subfamilies, that are now represented only in termites and some of their relatives among roaches. Finally, there is the problem of the physiological relationship between the host and the intestinal microorganisms.

A conception of the variety and complexity of the Protozoa can be obtained from the figures accompanying this chapter (figs. 20–23). To one familiar with other members of the Mastigophora, the peculiar characteristics of most of the forms in termites are striking. Almost all of the free-living flagellates have only one or two flagella, and most parasitic forms in other animals have

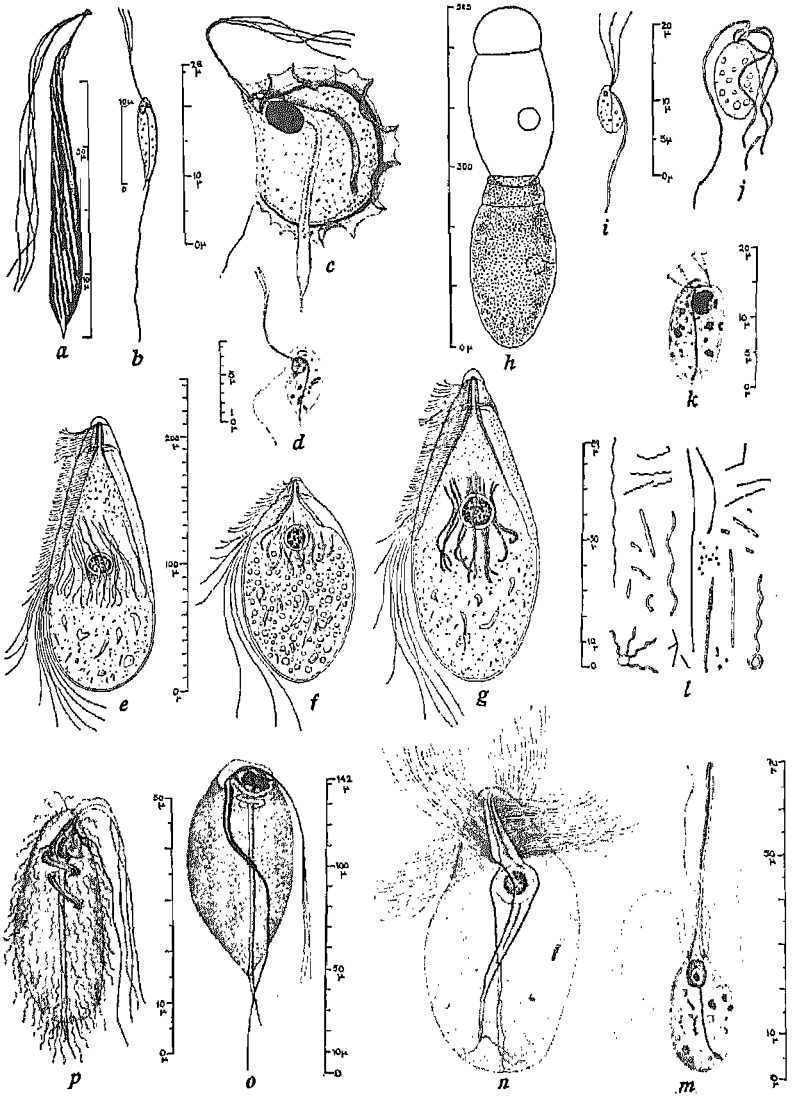

Fig. 20. *a–h.* From *Zootermopsis angusticollis*. *a. Streblomastix strix* Kofoid and Swezy, 1919. × 850. *b. Tricercomitus termopsidis* Kirby, 1930. × 1020. *c. Trichomonas termopsidis* Cleveland, 1925. × 908. *d. Hexamastix termopsidis* Kirby, 1930. × 1244. *e. Trichonympha campanula* Kofoid and Swezy, 1919. × 170. *f. Trichonympha sphaerica* (Kofoid and Swezy, 1919). × 170. *g. Trichonympha collaris* Kirby, 1932*a*. × 170. *h.* A gregarine, *Hirmocystis termitis* (Leidy). × 82. *i–k.* From *Kalotermes minor*. *i. Tricercomitus divergens* Kirby, 1930. × 1020; *j–k. Monocercomonas* sp. *j*, × 1020; *k*, × 932. *l.* Spirochaetes and bacteria from *Kalotermes hubbardi*. *m–o.* From *Kalotermes minor*. *m. Oxymonas minor* Zeliff, 1930. × 598. *n. Staurojoenina assimilis* Kirby, 1926. × 272. *o. Metadevescovina cuspidis* Kirby, MS. × 680. *p. Metadevescovina debilis* Light, 1926. × 680. From *Kalotermes hubbardi*.

from one or two to not more than eight, but on some of the flagellates in termites there are hundreds or thousands of flagella. Their internal organization is in many cases much more advanced in development than that of other Mastigophora.

Many of the spirochaetes and bacteria are normally found adherent to the surface of the flagellates. The kind of these microorganisms on the flagellates of one species is always the same. In some cases there are two kinds on an individual flagellate. On certain species there are rod-shaped forms which adhere to the surface by their full length, causing the flagellate to appear striated. Only one of the genera of flagellates found in California termites has such adherent rods. This is *Staurojoenina* (fig. 20*n*), on which the bacteria are very short.

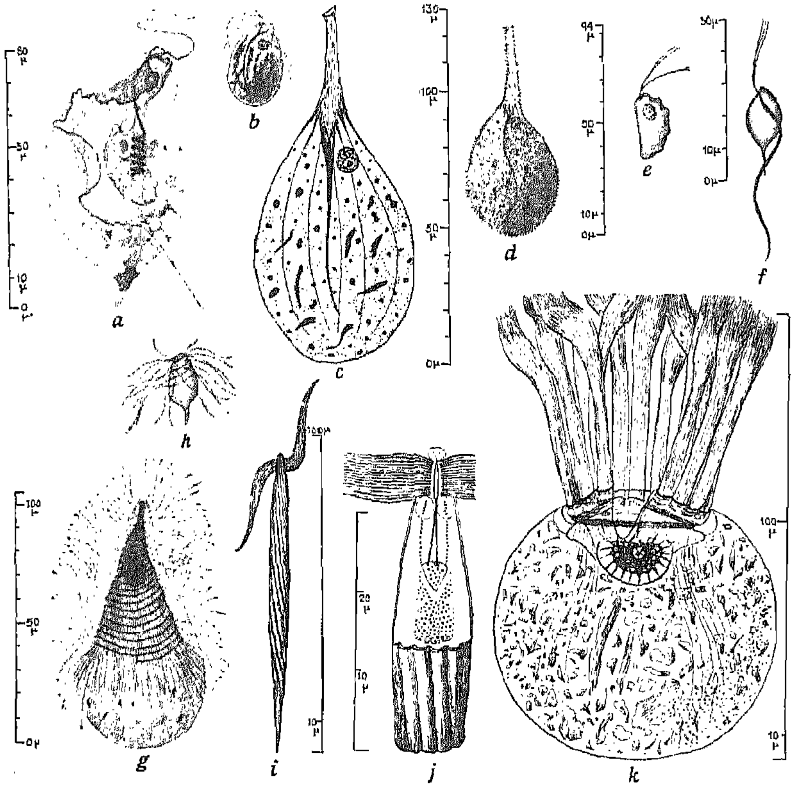

Fig. 21. *a–k*. From *Paraneotermes simplicicornis*. *a*. *Gigantomonas lighti* Connell, 1932. ×435. After Connell. *b–d*. *Oxymonas dimorpha* Connell, 1930; *b*, ×574; *c*. ×361; *d*, ×291. All after Connell. *e*. *Trichomonas* sp. ×425. *f*. *Janickiella* sp. ×425. *g*. *Spirotrichonympha polygyra* Cupp, 1930. ×319. After Cupp. *h*. *Spironympha* sp. ×425. *i–j*, *Hoplonympha natator* Light; *i*, ×425; *j*, ×1062. After Light. *k*. *Kofoidia loriculata* Light, 1927. ×319. After Light.

More common on local forms are microorganisms in the form of spirals and filaments which adhere each by one end, either in groups at the anterior and

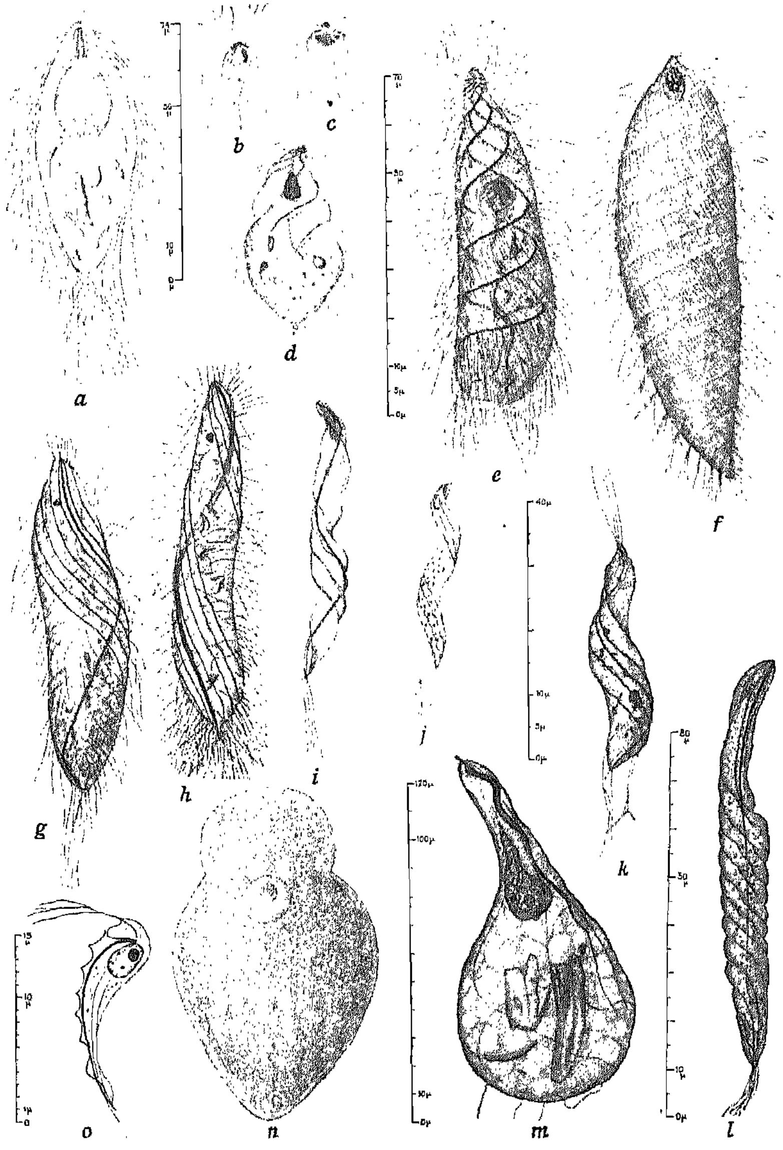

Fig. 22. *a–n*. From *Reticulitermes hesperus*. *a*. *Trichonympha agilis* Leidy, 1877. × 468. *b*. *Microjoenia ratcliffei* Brown, 1930. × 652. *c*. *Torquenympha octoplus* Brown, 1930. × 652. After Brown. *d*. *Spironympha porteri* Koidzumi, 1917. × 652. After Brown. *e*. *Spirotrichonympha flagellata* Grassi and Foa, 1911. × 652. *f*. *Holomastigotes elongatum* Grassi, 1892. × 652. *g–h*. *Dinenympha fimbriata* Kirby, 1924. × 652. *i–k*. *Dinenympha* sp. × 871. *l–m*. *Pyrsonympha major* Powell, 1928. × 1955. *n*. *Hirmocystis termitis* (Leidy, 1881). × 447. *o*. *Trichomonas trypanoides* Duboscq and Grassé, 1924. × 1700. After Duboscq and Grassé. Found in *Reticulitermes tibialis*.

posterior ends or all over the surface. Except for a few flagella at the posterior end, all of the thread-like bodies on *Dinenympha fimbriata,* shown in figure 22*g–h*, are adherent spirochaetes. This is also true of all the shorter spirals on the surface of *Metadevescovina debilis,* shown in figure 20*p*. In some of the literature adherent spirochaetes have been described as flagella. Comparison of the figures mentioned above with figure 22*d–f*, which show flagellates covered with true flagella, will indicate the difficulty involved in interpretation. Cleveland (1928) discovered that feeding the termites for a week or two on filter paper or ground wood moistened in a 5 per cent aqueous solution of acid fuchsin will result in the death of all the spirochaetes. By use of this method the true arrangement of flagella can easily be determined.

Many of the Protozoa have internal parasites of their own. These are bacteria and simple fungi. In *Trichonympha* from *Zootermopsis* (fig. 20*e–g*), there have been found six different parasites, most of which are infrequent, while one occurs in all individuals of two species. One fungus that is often encountered parasitizes the nucleus.

More than fifteen hundred species of termites are known, and doubtless many more exist. According to the presence or absence of abundant intestinal faunas of flagellate Protozoa, termites may be divided into two large groups. One group, comprising nearly four hundred species, contains all members of the families Mastotermitidae, Kalotermitidae, and Rhinotermitidae. About a third of these have been examined for Protozoa, and since every species has been found infected, it is highly probable that all members of the three families have abundant faunas.

The fourth family of termites, the Termitidae, contains about three times as many known species as the other three. Many which have been examined contain no Protozoa, while others have very few. A large group of wood-ingesting amoebae occurs in each of two species of *Mirotermes,* but complex flagellates like those in termites of the more primitive families have not been found in any Termitidae. The Protozoa of *Amitermes,* shown in figure 23*f–j*, are representative of those which have been found in termites of this family. In contrast to the situation in other termites, almost all of the infected Termitidae which have been examined have scanty faunas. The microorganisms of the flora, some of which in *Amitermes* are shown by figure 23*e*, are usually abundant.

There is much uniformity in the infection of different individuals of a termite community. Almost all termites of a species, except those at the period of molting, contain the same characteristic fauna. The exceptions are the very young, non-wood-feeding nymphs and the non-wood-feeding functional adults of the higher species. No matter where a termite of a given species occurs, examination of the gut will almost always reveal the same fauna of flagellates.

Most of the intestinal fauna is lost at the time of molting, but is quickly regained if normal contact with other individuals of the community is not prevented. The problem of refaunation in *Zootermopsis* has been studied by Miss B. J. Andrew (1930), whose work is summarized in chapter 6 (p. 70). Most Protozoa in animals are transmitted from host to host as resistant

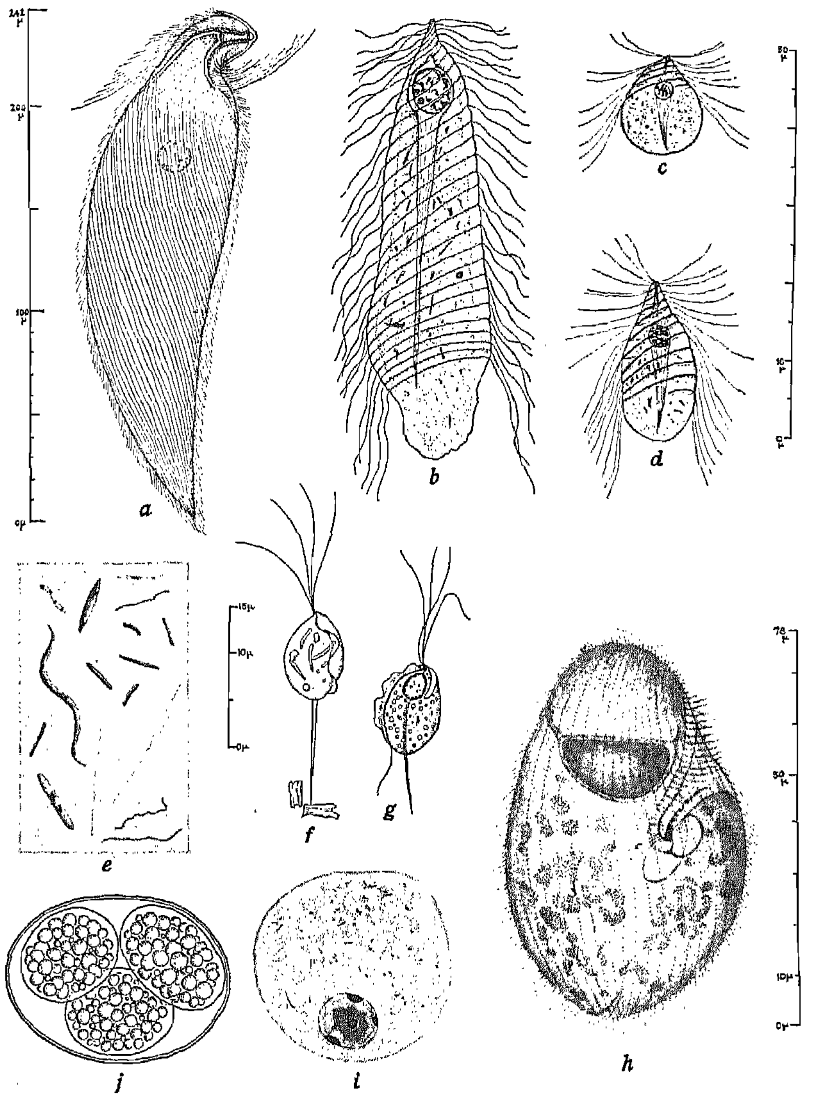

Fig. 23. *a–d*. From *Heterotermes aureus*. *a*. *Pseudotrichonympha* sp. × 276. *b*. *Holomastigotoides* sp., probably *hemigymnum* Grassi, 1917. × 276. After MacKinnon. *c–d*, *Spironympha* sp., probably *elegans* MacKinnon, 1927. × 1020. After MacKinnon. *e*. Bacteria and spirochaetes from *Amitermes beaumonti*. × 1244. *f–g*. *Trichomonas lighti* Kirby, 1932. × 1244. From *Amitermes wheeleri*. *h*. *Nyctotherus silvestrianus* Kirby, 1932. × 660. From *Amitermes silvestrianus*. *i*. *Endamoeba beaumonti* Kirby, 1932. × 1244. From *Amitermes* beaumonti. *j*. Oocyst of coccidian from *Amitermes minimus*. × 1244.

cysts. *Nyctotherus* in *Amitermes* forms cysts, but none of the flagellates in termites is known to do so. The active flagellates are passed directly from one termite to another in some manner that is not clearly understood. In nature it is doubtful if there has been any transfer of flagellates from one host species to another. Almost all of the evidence gained from consideration of their distribution in termites is against this possibility. Light and Sanford (1928), however, showed that under experimental conditions flagellates of *Zootermopsis* could survive in defaunated nymphs of *Kalotermes hubbardi* for at least a hundred days.

Flagellates similar to some of those in termites have been reported by Cleveland, Sanders and Hall (1931) from the wood-boring roach, *Cryptocercus punctulatus*. In the roaches the genus *Trichonympha*, which is widely distributed in termites, is represented by several species. Probably, then, relatives of the flagellates of termites were present in the primitive common ancestors of roaches and termites, which are believed to have existed in the late Paleozoic era. In some of them there has been little change since that time. *Trichonympha* is an example of the persistence of generic characters during many millions of years. Other groups of flagellates seem to have undergone evolutionary development in special groups of termites.

The evolution and distribution of flagellates in termites has taken place in such a manner that now certain genera and, in some cases, subfamilies of termites have characteristic and highly distinctive faunas. *Reticulitermes* in all parts of its range has a fauna very similar to that of the local *R. hesperus*, and this is very different from the fauna of any other genus of termites. Wherever found, *Heterotermes* has, it seems, a characteristic group of flagellates, which resembles that in *Coptotermes* and related genera. On the other hand, in the termites which usually have been grouped into the genus *Kalotermes*, and have not yet been distributed into subgenera or genera in an entirely satisfactory manner, the faunas show much variation. The Protozoa may be expected to aid greatly in showing the true relationships of termites of this group. Thus the faunas of *Kalotermes hubbardi* and *K. minor* clearly indicate a close relationship of their hosts, while that of *Paraneotermes simplicicornis*, which formerly was placed in the same subgenus, indicates a wide separation.

If the protozoan fauna is known, an examination of it provides a ready aid in systematic determination of the host. The two California species of *Kalotermes* and the related *Paraneotermes* can easily be separated by examination of the gut contents, and the other termites can at once be assigned to the proper genus. It is not possible, however, to distinguish between the California species of *Zootermopsis*, *Reticulitermes*, or *Amitermes* by this method. *Z. laticeps* of Arizona has a fauna in part unlike that of the two local species of the genus.

The problem of the physiological relationship between the microorganisms and their hosts has been studied intensively by L. R. Cleveland (1924–1928). When two organisms of different species are intimately associated, the relationship may be one of commensalism, in which only one member, if either, benefits; symbiosis, in which there is mutual benefit; or parasitism, in which one member suffers injury. According to Cleveland's demonstration, the association of termites and many of their flagellates is one of symbiosis.

The first step in this demonstration was observation of the fact mentioned above that the Termitidae, which usually derive their sustenance from other sources than cellulose alone, as humus, the organic matter in soil, and fungi, usually lack Protozoa, while the other termites, which feed on wood, have abundant faunas.

Methods of removing the intestinal microorganisms without apparent injury to the host were then discovered. Incubation at 36° C. for 24 hours, or starvation for a prolonged period, were successful in part. The most satisfactory method was found to be the placing of the termites in a chamber containing almost pure oxygen, usually under pressure of 3 to 4 atmospheres, for from ½ hour to 1 hour or more. By this treatment, in a period of time varying according to the pressure used, the microorganisms in the gut were killed. Andrew (1930) found a longer time than Cleveland (1925) recommended necessary for killing all the flagellates in *Zootermopsis*. She used a pressure of 45 to 50 pounds for 2½ to 3 hours, followed by oxygen alone for 24 hours.

There is considerable variation in the period of survival of different species of termites deprived of their intestinal Protozoa, but with the usual diet of sound wood or cellulose filter paper, which under normal conditions is said to be satisfactory for many termites, all species used in Cleveland's experiments ultimately died. *Reticulitermes* lived for about ten days to three weeks, *Zootermopsis* from three to four weeks, and seven species of Kalotermitinae for from nineteen days to nearly twenty-four weeks. One species survived on a diet of paper for a minimum of eighteen weeks.

In the earlier experiments on *Reticulitermes* in which the method of defaunation was incubation, when the defaunated termites were reinfected with Protozoa they continued to live indefinitely. They were also able to survive, at least for a long period, when fed humus or cellulose partly digested by fungi. The experiments in feeding fungus-digested cellulose were discontinued after two months, those in humus-feeding after from two to four months. In some experiments defaunated humus-fed termites were put on a sound wood diet after three to six weeks, whereupon they died in ten to twenty days. When decayed wood, in which, presumably, there is some predigestion by fungi, was fed to *Reticulitermes* defaunated by oxygenation, some lived for nearly ten weeks.

Cleveland (1928) states that no injury is suffered by termites defaunated by oxygenation. The Kalotermitinae, some of which survived for nearly six months, were treated in this way. Andrew (1930), who used much longer periods of exposure to defaunate *Zootermopsis*, found that the termites were not unharmed by the treatment. She states: "The death rate in the defaunated colonies is from three to ten times as great as in the faunated, normal colony, and such deaths occur long before the termites would begin to die of starvation."

These experiments show that the termites of the species used were unable to survive on a diet of the cellulose of wood or paper after removal of the flora and fauna of intestinal microorganisms by incubation or oxygenation, but some of them, at least, could survive if reinfected or given another diet. Why some are able to live on cellulose longer than others is not known. The experiments indicate that the tissues of the termites so investigated produce no cellulose-digesting enzymes.

Attempts to isolate cellulose-digesting bacteria from the intestines of termites were made by Cleveland (1924), Beckwith and Rose (1929), and Dickman (1931). Neither Cleveland nor Dickman was able to cultivate such bacteria. Beckwith and Rose claimed to have demonstrated the presence of cellulose-digesting forms, but Dickman points out that they did not use an adequate technique in sterilizing their material for the elimination of surface microorganisms. Dickman was able to isolate cellulose-digesting bacteria and molds from the wood inhabited by termites, and such forms would be present on the exterior of the termites.

By putting some acid fuchsin on the food of the insects, Cleveland was able, as mentioned above, to bring about removal of all the spirochaetes without apparent injury to the Protozoa. The termites so treated and subsequently fed upon cellulose continued to live normally for three months. This experiment indicates that the spirochaetes are not essential to the nutrition of their hosts.

The evidence, then, points to the conclusion that many of the flagellates are symbiotic, acting upon the wood so that some of its substance is made available for nutrition of the host. The host benefits the Protozoa by providing a favorable environment for their shelter and development. Other non-wood-feeding Protozoa are commensals.

The illustrations accompanying this chapter show all of the genera and most of the species of Protozoa known to occur in California termites. In order to indicate size, each figure is accompanied by a scale of microns, except that where several figures in a group have the same magnification only one scale is given. References to most of the literature on Protozoa in termites can be found in the articles by the writer (Kirby, 1926, 1931, 1932*a*, *b*) cited in the bibliography of this report. For the gregarines see Henry (1933).

A List of the Protozoa in Termites from California

In *Zootermopsis angusticollis* the following Protozoa have been found: *Streblomastix strix*, *Tricercomitus termopsidis*, *Trichomonas termopsidis*, *Hexamastix termopsidis*, *Trichonympha campanula*, *Trichonympha sphaerica*, *Trichonympha collaris*, and two gregarines, *Hirmocystis termitis* and *Kofoidina ovata*.

Zootermopsis nevadensis has a protozoan fauna identical with that of *Z. angusticollis*.

Kalotermes minor has the following Protozoa: *Tricercomitus divergens*, *Monocercomonas* sp., *Oxymonas minor*, *Staurojoenina assimilis*, and *Metadevescovina cuspidis*.

Kalotermes hubbardi contains *Tricercomitus divergens*, *Staurojoenina* sp., *Oxymonas hubbardi*, and *Metadevescovina debilis*. Fig. 20*l* shows forms of spirochaetes and bacteria from this termite. There are comparable microorganisms in other termites.

Paraneotermes simplicicornis contains *Gigantomonas lighti*, *Oxymonas dimorpha*, *Tricercomitus divergens*, *Trichomonas* sp., *Janickiella* sp. *Monocercomonas* sp. *Spirotrichonympha polygyra*, *Spironympha* sp., *Hoplonympha natator*, and *Kofoidia loriculata*.

Reticulitermes hesperus has a long list of intestinal Protozoa as follows: *Trichonympha agilis, Microjoenia ratcliffei, Torquenympha octoplus, Spironympha porteri, Spironympha ovalis, Spirotrichonympha flagellata, Holomastigotes elongatum, Dinenympha fimbriata, Dinenympha* sp., *Pyrsonympha major, Pyrsonympha minor, Pyrsonympha granulata,* and *Hirmocystis termitis.*

The intestinal fauna of *Reticulitermes tibialis* appears to be identical with that of *R. hesperus,* but it has not been studied in detail. The writer has observed *Trichomonas trypanoides* in this termite but not in *R. hesperus.*

Heterotermes aureus contains *Pseudotrichonympha* sp., *Holomastigotoides* sp., *and Spironympha* sp.

In the genus *Amitermes* relatively few Protozoa have been recorded. *Trichomonas lighti* has been found in all species of *Amitermes* examined, namely, *Amitermes emersoni, Amitermes coachellae, Amitermes minimus, Amitermes silvestrianus,* and *Amitermes wheeleri. Endamoeba beaumonti* has been recorded in *Amitermes coachellae, Amitermes minimus,* and *Amitermes wheeleri. Nyctotherus silvestrianus* has been found in *Amitermes silvestrianus, Amitermes minimus,* and *Amitermes emersoni.* A coccidian has been found in one individual of *Amitermes minimus.* Figure 23*e* shows bacteria and spirochaetes from *Amitermes beaumonti.* These and the amoeba figured from *A. beaumonti* of Panama also occur in local species of *Amitermes.*

CHAPTER 8

HYDROGEN-ION CONCENTRATION IN THE TERMITE INTESTINE

BY

MERLE RANDALL and THOMAS C. DOODY

Termites utilize mainly wood and similar fibrous products as a food material. Comparatively few animals are able to obtain nourishment from wood and the process by which this is accomplished is of great interest. Analyses of the wood used as food and the fecal residues, as reported by Oshima (1923), show that the termites utilize chiefly the cellulose. The results of the analyses are:

	Wood	Fecal material
Cellulose	54.6 per cent	18.0 per cent
Pentosans	18.0 per cent	8.5 per cent
Lignin, etc.	27.4 per cent	73.5 per cent
	100.0 per cent	100.0 per cent

Cellulose is a difficultly soluble polysaccharide of the general composition $(C_6H_{12}O_5)_n$. Its composition is similar to that of starch, but the molecular groups are larger and more complex, and its chemical structure is broken down only under very severe treatments. This has been accomplished to a considerable extent by hydrolysis in acid solution and by the action of certain bacteria or the enzymes produced by them. A knowledge of the means by which the termite is able to digest cellulose, or of the digestive processes of this insect in general, should give valuable clues to the proper chemicals for controlling its ravages.

The digestive processes of termites are extremely complex and by no means completely understood. The gut of all termites, except those of the family Termitidae, is filled with Protozoa, bacteria, and fungi, which probably assist in the digestion of cellulose. Certain of the Protozoa ingest the minute particles of wood in large quantities and evidently partially digest them. Certain types of these intestinal protozoan parasites have been shown by Cleveland (1925) to have symbiotic, or mutually beneficial, relations in the digestive processes of the termite. After the Protozoa have been killed by exposing the termites to oxygen gas, the termites themselves die, apparently from starvation. By refaunating before death with certain Protozoa the termites which were subjected to the oxygen treatment live on normally. This shows a definite relation of these Protozoa to the process of digestion. The wood particles in the gut contents are observed being ingested into the bodies of the Protozoa and are eventually passed back into the intestinal fluid. Little more than this is known about the digestion of cellulose. What treatment by the secretions of the digestive cells the wood particles must undergo before they can be ingested by the Protozoa, what chemical process in the digestion of cellulose the Protozoa take care of, what the products of this digestion are, and what purposes the bacteria and fungi serve, are all as yet largely unsolved problems in the utilization of cellulose as food.

Beckwith and Rose (1929) have studied eighty-five cultures from the digestive tracts of eight species of termites belonging to six genera, to test the digestion of the cellulose in filter paper. Such digestion was detected in only eleven of the eighty-five cultures. The flora of these cultures was composed of gram negative rods and some micrococci. None of the cultures showed either spirochaetes or Protozoa. These tests indicate that in the digestive tract of individual termites there is, at least occasionally, a bacterial flora which can destroy cellulose. The universal presence of such a flora was not detected.

A study of the acid concentration in the termite gut was made for the practical purpose of ascertaining whether acid-soluble poisons or wood preservatives might be expected to succeed in termite control, and in the hope of obtaining some further clue to the processes of digestion.

The quantities of liquid available from the termite intestine were so extremely small that it was difficult to use any of the standard micro methods for the determination of acid concentrations (p_H). The presence of the intestinal Protozoa, which are known to be very sensitive to changes in osmotic pressure or salt concentrations, forbade the dilution of the gut contents. Immediate disintegration of the protoplasm of the cell on the death of the Protozoa is known to produce quick changes in the p_H of the medium.

Because of the viscous nature of the intestinal fluid and the small amount of it available it was not possible to use the indicator paper, as proposed by Haas (1919), the drop method of Felton (1921), or the capillary pipette method of Wigglesworth (1927).

It was, however, possible to use the powdered indicator dye, as proposed by Sanford (1918), in the examination of the p_H of the alimentary canal of the cockroach. In this method powdered indicator dye is mixed with the food, and when the insects are dissected it is possible to trace the changes in p_H along the alimentary canal. This method is available in determining the acid concentrations throughout the digestive process of the termite, as well as at any point. The termites are easily kept in the laboratory on a diet of paper and it is a simple matter to feed them on a series of indicator papers.

The insects used throughout these tests were the damp-wood termites, *Zootermopsis angusticollis*. It was found advisable in these color tests to feed the insects on plain white filter paper for a week or more before starting them on the colored indicator papers. Thus all the variously colored wood particles are removed from the gut and do not confuse the color changes due to the acid indicators.

Preparation of indicator papers.—Observations on the types of filter paper available showed that the common paper contained carbonates and gave a somewhat alkaline reaction. Ashless type filter papers usually showed excess acid. It was found advisable to treat all filter paper used, both as colorless food and in the preparation of indicator papers. Common filter paper was first given an acid wash in dilute hydrochloric acid, followed by repeated washing in distilled water until it showed a neutral reaction, and was then dried.

Indicator papers were made in both acid and alkaline coloration with the following indicators. The p_H values are those at which the color changes take place.

Methyl orange (red, yellow)	p_H 3.1 and 4.4
Congo red (blue, red)	p_H 3.0 and 5.0
Bromcresol purple (yellow, purple)	p_H 5.2 and 6.8
Phenol red (yellow, red)	p_H 6.8 and 8.4
Thymol blue (yellow, blue)	p_H 8.0 and 9.6

The indicator papers were made by dipping the washed filter papers separately in solutions of the indicators and drying them. The methyl orange solution was made by dissolving 1 gm. of methyl orange in 1000 cc. of distilled water and filtering the solution. The Congo red was prepared by dissolving 0.5 gm. in 90 cc. of distilled water and 10 cc. of alcohol. The sulfonphthalien, or Clark and Lubs (1917) indicator solutions, were prepared as recommended by Clark (1928). For the bromcresol purple 0.1 gm. of the indicator was ground with 18.5 gm. of 0.01 normal sodium hydroxide. This was then diluted to 250 cc. to make a 0.04 per cent solution. The phenol red and thymol blue were made similarly, but 28.2 cc. and 21.5 cc. of 0.01 normal sodium hydroxide had to be used, respectively. Some difficulty was experienced in making these sulfonphthalien indicator papers, particularly the bromcresol purple. Some had to to be dipped and dried several times to obtain a permanent strong color of the indicator. Drying in air free of carbon dioxide made the preparation easier. The acid and alkaline types of paper were made by changing the colors of the indicator solutions by adding drop by drop very dilute solutions of sulphuric acid or sodium hydroxide, respectively, as desired. Delicate tints of indicator papers were unsatisfactory. Strong colors and strong color changes were required for identification by microscopic examination.

Procedure.—The termites were fed on the indicator papers for from one to three weeks before being examined. Two or three drops of distilled water were put on the papers every few days to keep the moisture at the optimum level.

For examination the entire gut was removed from the termite and placed on a slide. Observations of the color of the indicator were made under a low power microscope, although the color changes along the alimentary canal were often so striking that no magnification was required. The gut was then divided into its main divisions, oesophagus, crop, mid-intestine, and hind-intestine. After the record was made, each section was macerated and a drop of dilute acid or alkali, as required, added to change the color of the indicator, and to prove the presence of the indicator as an unchanged chemical substance. This color change was helpful where the presence of bits of indicator paper was doubtful, as was often the case in the hind-gut, where the Protozoa were very numerous.

When the gut contents were acidified there was always a strong odor of acetic or similar organic acid of low molecular weight. This hints strongly at the production of acetates or butyrates in the digestion of cellulose.

RESULTS

Methyl orange, yellow (alkaline): no color change, therefore

p_H—oesophagus > 2.9; crop > 2.9; mid-gut > 2.9; hind-gut > 2.9.

Methyl orange, red (acid): color change throughout, therefore

p_H—oesophagus > 4.4; crop > 4.4; mid-gut > 4.4; hind-gut > 4.4.

In both tests the indicator was proved to be present and unharmed. The termites which had been living on the methyl orange paper for much longer than one week showed the large Protozoa *Trichonympha campanula* (chap. 7), greatly diminished in numbers, and in some cases almost absent. The other Protozoa were affected, but not to the same extent.

Congo red, red (alkaline): no color change, therefore

p_H—oesophagus > 3.0; crop > 3.0; mid-gut > 3.0; hind-gut > 3.0.

Congo red, blue (acid): color red in oesophagus, crop, and mid-gut; then very blue at juncture of mid-gut and hind-gut, and lighter blue in hind-gut (fig. 15 *(2)*), therefore

p_H—oesophagus > 5.0; crop > 5.0; $>$ mid-gut 5.0; hind-gut between 3.0 and > 5.0 and evidently greater than 3.0.

At the junction of mid-gut and hind-gut the p_H was less than 3.0, but the condition in the hind-gut was progressively more alkaline thereafter through the colon and rectum.

The results with Congo red papers appeared contradictory at first. Several repetitions of the tests were made, but the averages gave these results consistently. The strong contrasting colors were easily discernible. Termites fed on blue (acid) Congo red paper showed the red color of the indicator in the gut, contrasted on the blue background, even through the chitinous body wall. The failure of the red (alkaline) Congo red paper to show a color change at the acid zone between mid-gut and hind-gut is explained by the fact that there could not have been enough acid to overcome the alkalinity of the oesophagus and also that of the indicator itself. As mentioned before, strong coloration was required in these observations, so that indicator concentrations larger than ordinary were used.

Bromcresol purple, purple (alkaline). The yellow color of this indicator in acid was difficult to identify with certainty where there was no striking contrast. The indicator was purple in the oesophagus, lighter in the crop and mid-gut, becoming deeper in color again toward the rear of the hind-gut, therefore

p_H—oesophagus > 5.2; crop, near but less than 5.2; mid-gut $<$ 6.8; hind-gut increasing to > 6.8.

Although the colors were faint, a check of the indicator showed it to be present unchanged in the digestive process. This helped to confirm the color indications.

Bromcresol purple, yellow (acid). The color changes in the gut were more conclusive with the yellow bromcresol purple paper. The indicator was purple in the oesophagus, yellow in the crop and mid-gut, becoming a deeper purple toward the rear of the hind-gut, therefore

p_H—oesophagus > 6.8; crop < 5.2; mid-gut < 6.8; hind-gut increasing to > 6.8.

Phenol red, red (alkaline). No trace of the red color remained; the indicator was yellow throughout the digestive tract. On standing, a red color developed in the oesophagus only, probably due to some decomposition process. Although the p_H of the oesophagus was less than 6.8, it was no doubt near that value, therefore

p_H—oesophagus near 6.8; crop, mid-gut, and hind-gut < 6.8.

Phenol red, yellow (acid): Color yellow throughout, therefore
p_H—less than 8.4 throughout.

Thymol blue, blue (alkaline): Color yellow throughout, therefore
p_H—less than 8.0 throughout.

Thymol blue, yellow (acid): Color yellow throughout, therefore
p_H—less than 9.6 throughout.

TABLE 3

TABULATION OF ACID CONCENTRATION, AS p_H, IN THE GUT OF *Zootermopsis angusticollis*

Indicator paper	Fore-gut	Crop	Mid-gut	Juncture of mid-gut and hind-gut	Hind-gut
Methyl orange					
yellow (alkaline)	>2.9	>2.9	>2.9	…………	>2.9
red (acid)	>4.4	>4.4	>4.4	…………	>4.4
Congo Red					
red (alkaline)	>3.0	>3.0	>3.0	>3.0?	>3.0
blue (acid)	>5.0	>5.0	>5.0	<3.0	>5.0
Bromcresol purple					
purple (alkaline)	>5.2 near	<5.2	<6.8	incre	asing>6.8
yellow (acid)	>6.8	<5.2	<6.8	<6.8 incre	asing>6.8
Phenol red					
red (alkaline)	<6.8	<6.8	<6.8	<6.8	<6.8
yellow (acid)	<8.4	<8.4	<8.4	<8.4	<8.4
Thymol blue					
blue (alkaline)	<8.0	<8.0	<8.0	<8.0	<8.0
yellow (acid)	<9.6	<9.6	<9.6	<9.6	<9.6
Final limits	>6.8<8.0	>5.0<5.2	>5.0<6.8	<3.0	>5.0<6.8
Average values	6.8	5.2	5.2	3.0	6.8

>Greater than <Less than

Discussion.—The work on the determination of the acid concentration in the termite gut is far from complete. It could well be extended with other indicators to narrow the limits between which the p_H of the various gut sections has been established, and to check the present measurements.

The oesophagus has been shown to have nearly neutral contents, probably just slightly acid with a p_H of 6.8.

The p_H of the crop seems rather definitely to be between 5.0 and 5.2, having most probably a value near 5.2.

The range of p_H in the mid-gut is probably between 5.0 and 6.8.

One group of experiments proves that at the junction of the mid-gut and hind-gut the p_H is less than 3.0 and probably very near that value. Nevertheless, the results were definite and the strong acid condition is believed to be established.

In the hind-gut the condition becomes progressively more alkaline toward the rectum, probably reaching an almost neutral condition at a p_H of 6.8.

Of the indicators used in these experiments, methyl orange was the only one which showed a decided toxic effect on the intestinal Protozoa. The sulfonphthalien indicators have been used in insect physiology most extensively because of their low toxic effects.

Zootermopsis fed continuously on indicator paper for a period of three weeks or more showed a disturbance of the normal p_H in the alimentary tract. Indicators are themselves weak acids and bases and the continuous diet of such materials, often in considerable concentrations, would be expected to produce this effect.

CHAPTER 9

THE ASSOCIATION OF TERMITES AND FUNGI

BY

ESTHER C. HENDEE

It has long been recognized that termites may be associated with the work of fungi. *Zootermopsis* is often called the "rotten-wood" termite. *Reticulitermes* is reported as working either in decayed wood or in apparently sound wood. *Kalotermes*, however, is usually observed in wood which superficially appears to be free from fungous attack.

The questions which center around this relationship of termites and fungi are of both economic and biological interest. Are fungi always associated with termites? Is a particular fungus found with a particular termite? Is the association due merely to a similarity of habitat, or do the termites and fungi benefit or harm each other? Do termites aid in the spread of fungi? Do the fungi change the wood in such a way as to make it more attractive to the termite? Do the fungi serve as food for the termites? The source of the nitrogen supply for the termite has not been explained, and the possibility of a symbiosis in this connection is suggested. Many fungi are capable of digesting cellulose. Hence, their presence either in the habitat or in the digestive tract of an animal whose diet consists largely of wood becomes of interest.

The present investigation has involved a survey of the numbers and kinds of fungi associated with 15 colonies of *Kalotermes minor* Hagen, 12 colonies of *Reticulitermes hesperus* Banks, and 12 colonies of *Zootermopsis angusticollis* Hagen. A study has also been made of the distribution of the fungi in and on the termites, and in the habitats of individual termite colonies. It is hoped that the results of this work may offer a basis for further study of the *significance* of the association of termites and fungi.

The three species of termites studied represent the three important habitat types. The colonies were collected in various localities and occurred in at least eleven species of wood. Some of the wood was so badly decayed that the species could not be determined with certainty.

Two hundred fifty-eight fungous cultures were made from the 15 colonies of *Kalotermes minor*, 120 from the 12 colonies of *Reticulitermes hesperus*, and 120 from the 12 colonies of *Zootermopsis angusticollis*. In speaking of the isolation of fungi from a termite colony, the word colony is used to include not only the termites themselves, but also their fecal pellets, loose detritus or frass within their burrows, and the wood of the walls of the burrows.

From these cultures, representatives of 33 genera of fungi were isolated and identified to the genus. Twenty other fungous cultures which were isolated failed to produce spores. Of these twenty, 6 were identified as to class by certain characters of the hyphae. The other 14 could not be placed at all from the vegetative stages in which they grew in the cultures.

FUNGI ASSOCIATED WITH THE DIFFERENT SPECIES OF TERMITES

In order to learn what fungi were most frequently associated with *Kalotermes minor, Reticulitermes hesperus,* and *Zootermopsis angusticollis,* and to determine whether any particular fungus or group of fungi was associated with a given species of termite, data resulting from 10 cultures taken from each of 12 colonies of each of the three species of termites were considered.

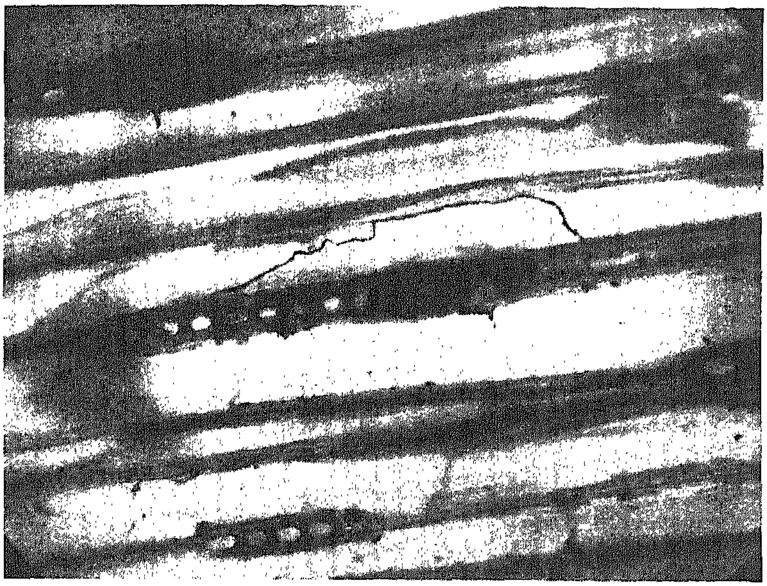

Fig. 24. Photomicrograph showing minute fungous hyphae in the wood of the wall of a gallery of *Kalotermes minor*. Section from the rough surface of gallery located in the apparently sound, dry wood of a Port Orford cedar pole. × 360. From Hendee (1933, fig. 1).

These cultures were taken from surface wood of the walls of galleries and from wood 1–2 mm. below the surface of the walls of galleries of all three species of termites, also from the fecal pellets of *K. minor* and *Z. angusticollis,* and from the frass with which *R. hesperus* stops up abandoned galleries.

From these 360 cultures, fungi belonging to 29 genera were isolated, besides 14 non-sporulating and therefore undetermined fungous cultures.

Of the 29 genera identified, 12 were isolated from colonies of each of the three species of termites studied, 11 from colonies of two species, and 6 from the colonies of one species. Those which were isolated from the colonies of only a single species were all of infrequent occurrence with that species.

Table 4 shows the genera of fungi which were most frequently found with *Kalotermes minor, Reticulitermes hesperus,* and *Zootermopsis angusticollis.* These are fungi which were isolated from at least 5 out of 12 colonies of at least one species of termite. No one of these genera of fungi was confined to the colonies of a single species of termite. *Penicillium* and *Trichoderma* were most widespread in their distribution in the cases of all three termites. They were also by far the most abundant within the individual colonies.

TABLE 4

FUNGI MOST FREQUENTLY ISOLATED FROM COLONIES OF *Kalotermes minor, Reticulitermes hesperus* AND *Zootermopsis angusticollis*

Genus of fungus	Number of colonies from which fungus was isolated		
	Kalotermes minor	*Reticulitermes hesperus*	*Zootermopsis angusticollis*
Penicillium	12	11	11
Trichoderma	10	11	12
Mucor	1	8	6
Mortierella	0	5	8
Tilachlidium	7	5	2
Oedocephalum	1	4	6
Catenularia	2	4	6
Leptographium	0	6	2
Oöspora	7	1	0
Acrostalagmus	0	5	2

The differences in the numbers of genera of fungi isolated from the colonies of the different species of termites were not great, 25 genera being identified among the isolations from *Reticulitermes hesperus,* 22 from *Zootermopsis angusticollis,* and 17 from *Kalotermes minor.* The number of genera of fungi isolated from the 10 cultures made from each individual termite colony ranged from 3 to 8 per colony for *K. minor,* from 4 to 13 for *R. hesperus,* and from 2 to 11 for *Z. angusticollis,* the average per colony being 5.08 for *K. minor,* 8.75 for *R. hesperus,* and 7.25 for *Z. angusticollis.*

The differences in amounts of fungous growth present in the colonies of the different termites were much more distinctive, colonies of *Kalotermes minor* showing much less luxuriant fungous growth than those of *Reticulitermes hesperus* or *Zootermopsis angusticollis.* This was indicated by (a) the differences in the total numbers of isolations from the colonies of the different termites; (b) the differences in the variety and abundance of growth resulting from individual inoculations of wood, pellets, or frass, onto the nutrient medium; and (c) the macroscopic and microscopic examination of the wood of the termite colonies. Upon macroscopic examination, the wood of the *K. minor* burrows sometimes revealed no indication of the presence of fungi. In some cases stains or structural defects, probably due to fungous attack, were visible, but in no case was there sufficient growth for the fungus itself to be visible to the naked eye. It could be revealed only by staining thin sections of the wood and subjecting them to microscopic examination. In the colonies of *R. hesperus* and of *Z. angusticollis,* on the other hand, there was often a mat-like fungous growth on portions of the gallery walls, or a web-forming growth over the fecal pellets or frass. The smaller amount of fungous growth associated with *K. minor* was what would be expected from the relatively greater dryness of the wood containing their colonies as compared to that containing the colonies of *R. hesperus* or *Z. angusticollis.*

No colony of any species of termite studied, in any wood, was without the presence of fungi in the walls of the burrows.

CLASSIFICATION AND NATURE OF THE FUNGI

Fungi belonging to four classes were found in association with each of the three genera of termites.

(1) Four genera of Phycomycetes were represented. Of these *Mucor* and *Mortierella* were among the more commonly occurring fungi, as may be seen in Table 4. The Phycomycetes are lower filamentous fungi, and have ordinarily been found to be incapable of fermenting cellulose. They are wood-inhabiting, but not typically wood-destroying forms. They follow spaces in the wood and seldom, if ever, penetrate lignified walls, or materially affect the structural character of the wood.

(2) Only one perfect form of the Ascomycetes was isolated. This was a member of the genus *Sordaria.* It was very abundant in two colonies of *Kalotermes minor* occurring in poles, but otherwise was infrequent. *Sordaria* is a form reported as commonly growing on dung. In the laboratory it grew profusely on cellulose media.

(3) The large majority of the fungi which were isolated are classed among the Fungi Imperfecti. The Fungi Imperfecti are forms reproducing by conidia and in many cases are known to be stages in the life histories of Ascomycetes. They include many wood-inhabiting forms. Some have been reported to be capable of penetrating lignified cell walls, but usually they follow natural or artificial spaces in the wood. While they are not typically wood-destroying fungi, some of them cause stains in wood. Others live in decayed wood as secondary saprophytes. Representatives of 24 genera of Fungi Imperfecti were found.

(4) A comparatively small number of Basidiomycetes was isolated. They do not produce spores on the artificial media and therefore cannot be easily identified. Six of the 20 non-sporulating cultures of fungi isolated were recognized by certain vegetative characters as being Basidiomycetes. They were isolated from 3 of 12 colonies of *Kalotermes minor,* 4 of 12 colonies of *Reticulitermes hesperus,* and 1 of 12 colonies of *Zootermopsis angusticollis.* It is probable that some of the other non-sporulating cultures may also have belonged to this class. Among the Basidiomycetes are found the true wood-destroying fungi. These fall into two groups: those which attack principally the lignin of the cell walls, and those which for the most part destroy the cellulose. The lignin-dissolving fungi usually cause what are known as white rots; the cellulose-dissolving fungi are responsible for most of the brown

rots. Still other Basidiomycetes are secondary saprophytes, developing in wood which is already decayed. The isolation of a basidiomycete from a piece of wood does not necessarily mean that the wood has undergone any considerable decay, since the stages of incipient decay are often quite prolonged. Hence, wood which is apparently sound may contain living fungi, which, in time, will effect visible damage to the wood. On the other hand, wood in late stages of decay may no longer contain the fungi which were responsible for the original decay. It is known that often the hyphae of a fungus disappear from wood when decay reaches a certain stage. They apparently undergo auto-digestion upon exhaustion of their food supply. Furthermore, a basidiomycete isolated from badly decayed wood is, in many cases, not the primary wood-destroyer, but a secondary saprophyte.

STATE OF THE WOOD CONTAINING THE TERMITE COLONIES

In view of the above facts, it becomes evident that the relation of Basidiomycetes to termites may be rather different from that indicated by the results of the isolations. It is of interest, therefore, to consider not only the fungous flora of the wood at a given time, but also the apparent condition of the wood as regards soundness or decay.

Five of the colonies of *Kalotermes minor* were in sound, dry wood showing no evidence of decay. No Basidiomycetes were isolated from these colonies. Four colonies were located in logs or stumps which were decayed on the outside or had decayed regions, but were apparently sound in the region of the termite galleries. Basidiomycetes were isolated from the wood adjacent to the galleries of two of these colonies. Three colonies were in wood showing a moderate amount of decay, but yielding no Basidiomycetes in culture. The wood containing one colony of *Kalotermes minor* was in an advanced stage of decay. The termites were found in a large gallery whose walls were so punky that they could be picked apart with forceps. No Basidiomycetes were isolated from this colony.

Two of the colonies of *Reticulitermes hesperus* were in apparently sound, but discolored wood, four in somewhat decayed wood, and six in wood in a late stage of decay. Basidiomycetes were isolated from two of the colonies of the last group.

One colony of *Zootermopsis angusticollis* was in sound, but somewhat discolored wood, and one in wood in an early stage of decay. Ten were in badly decayed wood, and Basidiomycetes were isolated from one of these colonies.

In brief, all three species of termites were occasionally found associated with living Basidiomycetes. *Kalotermes minor*, however, was ordinarily found in wood which had undergone little, if any, structural change from fungous attack. *Reticulitermes hesperus* and *Zootermopsis angusticollis*, on the other hand, were usually in wood which had been greatly harmed by wood-destroying fungi, but which, at the time of the termite occupancy, might contain only secondary saprophytes.

DISTRIBUTION OF FUNGI WITHIN INDIVIDUAL TERMITE COLONIES

The cultures made for the comparative study of fungi associated with *Kalotermes minor, Reticulitermes hesperus,* and *Zootermopsis angusticollis* yielded data on the occurrence of fungi in the wood of the surface of the gallery walls, in the wood at a distance of 1–2 mm. from the galleries, in the fecal pellets, and in the frass. In addition to this, a more detailed study was made of three colonies of *K. minor,* cultures being taken from wood of the surface of gallery walls, from wood at various distances from the galleries, from the exterior surfaces of termites, from the guts of termites, and from the fecal pellets. Fungi were isolated from all of these sources.

Cultures taken from the surface wood of gallery walls in general showed much greater amounts of fungous growth and considerably greater varieties of fungi than those from wood 1–2 mm. from the galleries. *Trichoderma* and *Penicillium* were about twice as abundant within the galleries as at a depth of 1–2 mm. Wood taken at distances of 1–10 mm. from the termite galleries in a Port Orford cedar pole containing a colony of *K. minor* yielded only 4 positive cultures out of 15. Of these 15, the 6 taken at distances greater than 2 mm. were all negative. The wood of the surface of gallery walls, on the other hand, yielded 16 positive cultures out of 17.

Thin sections of the wood were cut and stained to further demonstrate the presence of fungi in the wood. In the sound, dry wood of the pole hyphae were observed following the lumina of the cells near the termite galleries. Figure 24 is a photomicrograph of a section cut from the rough surface of a termite gallery. The minute fungous hyphae appear as slender dark lines.

The fecal pellets seemed to offer a good medium for fungous growth. About the same number of different fungi were isolated from them as from the wood of the gallery walls. Hyphae could be observed growing out from the surface of pellets. Their presence within the pellets was also demonstrated.

The frass from colonies of *Reticulitermes hesperus* yielded about the same number and kinds of fungi as wood of the walls of galleries.

Cultures made from the exterior surfaces of 17 individual termites gave positive results in 12 cases. No fungi were observed to be growing on the termites, however.

Out of 32 cultures made from the gut of *Kalotermes minor* 11 positive cultures were obtained. The fungi isolated were, with one exception, forms which were also isolated from the wood. A few smears made from the wall and contents of the gut were examined microscopically, but no fungi were observed in the case of termites taken from their natural habitat. Due to the large bulk of intestinal contents, a few small, hyaline spores might easily have escaped observation. Hyphae or germinating spores, if present in significant amounts, would have been much more likely to be seen.

RÔLE OF TERMITES IN THE SPREADING OF FUNGI

To test the ability of termites to carry fungi, a number of termites were put upon pure cultures of *Alternaria* sp., a fungus having large, dark-colored spores. Within 48 hours the termites were noticeably blackened by the spores; under the dissecting microscope it was possible to distinguish the individual spores. They were present by the hundreds on all parts of the body. Smears from the gut showed intact spores, fragments of spores, and a few fragments of hyphae. There was no indication of germination of spores or growth of hyphae. Cultures made from the guts of these termites yielded abundant growths of the fungi on which the termites had been feeding. Termites, in walking across cultures of the non-spore-bearing Basidiomycetes, accumulated large tufts of hyphae, which clung to their legs.

The spaces of the termite burrows offer opportunity for more abundant fruiting of fungi and for the spread of hyphae which do not readily penetrate lignified walls.

A comparison was made between the fungous flora of a pole uninfested by termites and that of one infested by *Kalotermes minor*. The two poles were of the same kind of wood and had similar histories of service. Twelve cultures made from heartwood of the pole uninfested by termites were all negative. Seventeen out of 27 made from sapwood were also negative. From the 10 positive cultures which had come from sapwood 1.5–6.0 mm. below the surface of the pole or of cracks, two fungi, *Sordaria* sp. and *Alternaria* sp., were isolated. In the termite-infested pole, 14 cultures taken at intervals throughout the diameter of the pole, 7 of them from the surface of walls of termite galleries, and 7 from wood 1–2 mm. below the surface of the walls of galleries, were all positive. The same two fungi, *Sordaria* sp. and *Alternaria* sp., which were found near the surface of the pole uninfested by termites were common in the second pole in both sapwood and heartwood adjacent to termite galleries. Nine other genera of fungi were also present, of which the most abundant was *Penicillium*.

We have, in a previous section, also noted the greater abundance of fungi within the termite galleries than deep in the wood. It seems evident, then, that termites may introduce fungi which were not previously present in the wood, and that they may aid in the spread through the wood of these and of others already present.

GENERAL OBSERVATIONS

The results of this investigation indicate that fungi are associated with *Kalotermes minor*, *Reticulitermes hesperus*, and *Zootermopsis angusticollis*. They were isolated from every termite colony studied. Their presence on the walls of the burrows and in the fecal pellets of the termites was demonstrated. Termites enlarge their burrows; they eat their fecal pellets; fungi would seem, therefore, to be a common element in their diet. Further investigation, however, will be necessary to indicate the *significance* of fungi as food for the termites.

A study should also be made of the value to termites of changes which fungi cause in wood. Fungi which are known to be capable of changing the chemical composition of wood may alter its mechanical structure. They may also alter its taste and odor. It is possible that the presence of fungi may be a factor of importance in the selection of a particular piece of wood, on the one hand, for the entrance of the primary pair, and, on the other, for the extension of colonies from the original site into the piece of timber selected.

SUMMARY

1. Fungi were isolated from each of the 15 colonies of *Kalotermes minor,* 12 colonies of *Reticulitermes hesperus,* and 12 colonies of *Zootermopsis angusticollis* studied.
2. Representatives of 33 genera of fungi and 20 non-sporulating fungous cultures were isolated from the colonies of the three species of termites.
3. A somewhat smaller number of fungi were associated with *Kalotermes minor* than with *Reticulitermes hesperus* and *Zootermopsis angusticollis,* 17 genera of fungi being isolated from 12 colonies of *K. minor,* as compared to 25 genera from 12 colonies of *R. hesperus,* and 22 genera from 12 colonies of *Z. angusticollis.*
4. The average number of genera of fungi isolated from ten cultures made from each of 12 colonies of each of the species of termites was 5.08 for *Kalotermes minor,* 8.75 for *Reticulitermes hesperus,* and 7.25 for *Zootermopsis angusticollis.*
5. A smaller amount of fungous growth was present in the colonies of *Kalotermes minor* than in those of *Reticulitermes hesperus* and *Zootermopsis angusticollis.*
6. There was no evidence of any specific relation between a given species of termite and any genus of fungus.
7. *Penicillium* and *Trichoderma* were the genera of fungi most frequently isolated from the colonies of all three species of termites.
8. The wood containing colonies of *Kalotermes minor* usually showed little structural injury from fungous attack, while that of *Reticulitermes hesperus* and *Zootermopsis angusticollis* usually showed decay.
9. Within the individual termite colonies fungi were isolated from the wood, the frass, the exterior surfaces of termites, their guts, and fecal pellets.
10. Termites were found to be capable of transporting fungous spores and hyphae.
11. Twelve cultures made from the heartwood of a pole uninfested by termites were all negative. Seventeen out of 27 made from the sapwood were also negative. In a termite-infested pole 14 cultures taken at intervals throughout the diameter of the pole adjacent to termite galleries were all positive.
12. Fungi were more abundant on the inner surface of termite galleries than away from the galleries, only 4 cultures out of 15 taken from wood 1–10 mm. below the surface of galleries of a colony of *Kalotermes minor* being positive, as compared to 16 positive cultures out of 17 taken from the surface of the gallery walls.

CHAPTER 10

A WORLD VIEW OF TERMITES

BY

S. F. LIGHT

While the termites constitute a separate order of insects, they are confined to a narrow ecologic range. With few exceptions they feed primarily upon cellulose in some form. All are social. All but a few species live in enclosed dwellings of their own construction shut off entirely from the light except as voluntarily opened for removal of pellets, extension of covered runways, or for swarming. They are also protected from many of the physical vicissitudes common to insects living in the open and from contacts with other competing and hostile organisms, and are therefore largely free from the attacks of predatory or parasitic animals and from bacterial diseases. The actual area traversed in the life of a termite is limited and, except for swarming, remarkably monotonous and uniform. As a natural result of the limitations in life range, the order consists of only about 130 genera and subgenera and 1,500 species, a relatively small number as compared to other orders of insects. The number of individuals, on the other hand, is very great, and the termites are actually dominant animals in certain parts of the tropics, as brought out below.

The termites have their greatest efflorescence in the tropics. There they interpenetrate their environment to the greatest degree, resulting in a wide range of varieties of habits and of habit types. There, naturally, are to be found by far the greatest number of different genera and of species. There colonies are extremely numerous and large, with populations of hundreds of thousands or even millions of individuals. There, also, building activities are carried on most extensively and in greatest variety of patterns. The great earthen mounds (fig. 25*a*), often many feet in height, and the structurally bizarre carton nests (figs. 25*c*, 37) of many types, constitute ever-present elements in the tropical landscape. There, also, their covered runways (figs. 25*b*, 95) are everywhere to be seen. By means of these the termites extend the favorable conditions of the home nest for considerable distances to foraging grounds in dead wood on the ground or high on great forest trees.

In the tropics the termites reap the harvest of wood and vegetation and there they are unquestionably a dominant animal type. Their weakness as individuals is offset by the secluded and protected existence they enjoy as a result of their concerted activity, and by their ability to utilize an ever-present food supply not available to most animals. These habits give them a tremendous advantage in the struggle for existence. The biologist, indeed, is amazed not at their numbers, but that, given these advantages, they do not

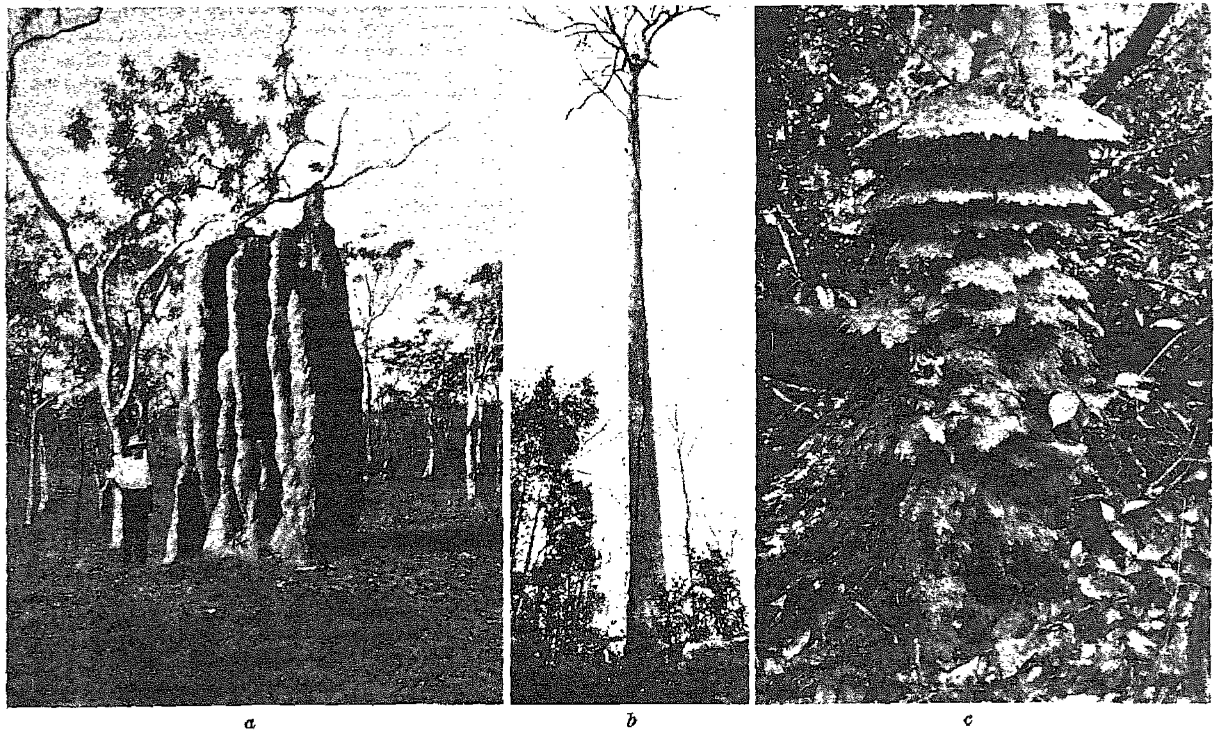

Fig. 25. Structures built by tropical earth-dwelling termites. *a*. Earthen mound of a nasute termite in northern Australia. *b*. The covered runways built by another nasute termite *(Nasutitermes fumipennis)* on the bark of a eucalyptus tree in North Queensland, running from the ground to its carton nest in the crotch of the tree more than 100 feet above the ground. Such covered runways are common sights in the tropics. From Mjöberg (1920, fig. 61). *c*. A carton nest of the umbrella type. Nests of this type are constructed around tree trunks in the forests of Africa and South America, and are seemingly designed to shed rain. This nest, built by an undetermined species in the Belgian Congo, extended about 4 feet above the ground. From Hegh (1922, fig. 1).

more nearly saturate their possible environment and destroy available wood more promptly and more completely.

There is every reason to believe that many species and even some genera of termites remain yet unknown. The collections made during the investigation of the termite fauna of western Mexico for the Termite Investigations Committee, for example, included twelve new species and one very distinctly new and different genus (chap. 28). Professor Sjöstedt's monograph on African termites (1925) presents descriptions of numerous new genera, and no doubt more comprehensive and intensive collecting in Central America, South America, Australia, Africa, India and the East Indies will bring to light many more new genera. For a comprehensive, well illustrated world view of the termites the reader is referred to *Les Termites* by E. Hegh (1922).

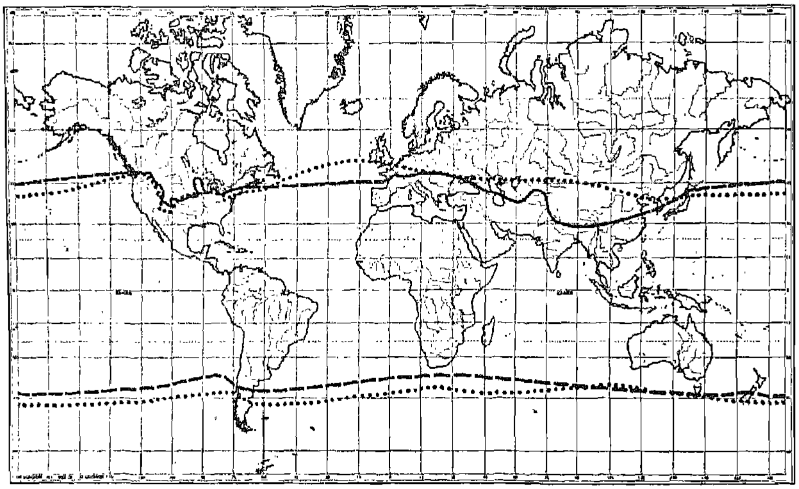

Fig. 26. A map, prepared by Prof. A. E. Emerson, showing the distribution of termites throughout the world. The heavy line marks the northern and southern limits; the dotted line, *the mean annual isotherm of 50° F.*

While the termites reach a maximum development in the true tropics, they are found in considerable numbers and variety in the subtropics. Some extend their range northward and southward into the warmer temperate regions, but only a few species are able to withstand the rigors of life in the colder portions of the temperate zones. However, in the north temperate zones species of the holarctic genus *Reticulitermes* are found beyond the fortieth parallel. The ameliorating effects of ocean currents have made for a far northward extension, also, of other genera and species, particularly along the western coast of America and the eastern coast of Asia.

The map (fig. 26) prepared by Professor A. E. Emerson, of the University of Chicago, is an attempt to indicate the general area of the globe inhabited by termites. The northern limits are well known in Europe and America, but are somewhat problematical as yet in Asia. In the southern hemisphere termites are found throughout Africa and Australia, but the southern limits for South America are largely a matter of conjecture. An extension on the average to the 50° mean annual isotherm, both north and south, is indicated by the facts in hand and emphasizes the controlling influence of climate.

Classification.—The termites constitute a separate order of insects, the Isoptera. The characterization given below is adapted from Imms (*Textbook of Entomology,* 1925). For the meaning of terms see figures 27–30.

DEFINITION OF THE ORDER ISOPTERA

Social and polymorphic insects living in large communities, composed of winged and/or short-winged and/or wingless reproductive forms, together with numerous wingless sterile soldiers and workers. Mouth parts of the typical biting type; ligula 4-lobed. Wings very similar, elongate and membranous, superposed flat over the back when at rest, and capable of being shed by means of basal fractures. Anterior veins strongly chitinized, regular cross veins wanting, but an irregular network often present. Genitalia wanting or rudimentary in both sexes [except in *Mastotermes*]. Metamorphosis slight or absent.

The first attempt at a monograph was that of Hagen (1855–60). The next notable system of classification was that of Holmgren (1911), which has given form to all succeeding classifications. Unfortunately, the names which Holmgren used for three of the families (Protermitidae, Mesotermitidae, Metatermitidae) did not conform to the accepted rules of nomenclature and were changed by Banks (Banks and Snyder, 1920). Banks, however, recombined the Mesotermitidae and Metatermitidae of Holmgren in his Termitidae. These two families were separated by Light (1921*b*) along the lines laid down by Holmgren, and given the names Rhinotermitidae and Termitidae. These were accepted by Emerson in his works on the termites of Kartabo in British Guiana (1925) and on the termites of the Belgian Congo and the Cameroon (1928). Sjöstedt in his *Revision der Termiten Afrikas* (1925) separated the family Hodotermitidae from the Kalotermitidae of previous workers and is followed in this by Emerson (1928). This gives us five families, as defined below.

Family I.—**Mastotermitidae** Silvestri, 1909. Fontanel absent in all castes; ocelli present (fig. 31); tarsi 5-jointed in all castes; hind-wings with a well developed anal lobe (fig. 31); genitalia well developed.

Here belongs a single primitive genus, *Mastotermes,* with a single living species, *M. darwiniensis* Froggatt from northern Australia (fig. 31). Several fossil species have been found in Europe. (See Snyder, 1925, for a résumé of fossil termites.)

The four remaining families have 4-jointed or, rarely, imperfectly 5-jointed tarsi in all castes, and hind-wings without an anal lobe; genitalia are lacking or vestigial.

Family II.—**Hodotermitidae** Sjöstedt, 1925. Fontanel and ocelli absent and pronotum saddle-shaped and narrower than the head in all castes; anterior wing scales (fig. 1*b*) short, not over-lapping the posterior wing scales, This family includes 15 species in 3 subgenera of the single genus *Hodotermes,* confined to Africa and Central Asia. They are large termites of subterranean habit which feed largely on grass, being among the few termites which forage abroad for their food. While primitive in many respects, the termites of this family show a higher social development than those of the next family (Kalotermitidae) in that they have a worker caste.

> *Family III.*—**Kalotermitidae** Sjöstedt, 1925. Fontanel absent in all castes; ocelli usually present; pronotum flat (as in fig. 27), usually broader than head in all castes; anterior wing scales large (fig. 27), over-lapping the posterior wing scales; no worker caste.

Here belong about 240 known species representing some 20 genera and subgenera, including the primitive genera *Archotermopsis, Hodotermopsis, Zootermopsis, Stolotermes,* and *Porotermes,* and the very large genus *Kalotermes,* consisting of 14 subgenera, some of which no doubt will be raised to generic rank. The Kalotermitidae are wood-dwelling termites. They found and maintain their colonies in wood without ground contact, often in sound, relatively dry wood. Included here are a number of termites of economic importance, such as the common dry-wood termites of western United States (chaps. 19–23), the common powder-post termite (p. 197), the tea termite of Ceylon (Jepson, 1929), and the teak termite of Java (Kalshoven, 1930). Here belong also the damp-wood termites of the genus *Zootermopsis* found in western North America (chap. 24). Keys to the American species of this family appear on pages 199–200.

> *Family IV.*—**Rhinotermitidae** Light, 1921. Fontanel present (fig. 2); mandibles of so-called *Leucotermes* or *Serritermes* type (see Holmgren, 1911); anterior wing scale large (except in *Psammotermes*); wing often reticulate and without hairs; pronotum of worker and soldier flat, without anterior lobe (fig. 1).

To this family belong about 140 species, representing 12 genera and subgenera as follows: *Psammotermes, Heterotermes* (=*Leucotermes*), *Reticulitermes, Stylotermes, Prorhinotermes, Coptotermes, Termitogeton, Parrhinotermes, Rhinotermes, Macrorhinotermes, Schedorhinotermes, Serritermes.*

With the exception of the species of *Prorhinotermes,* which are damp-wood termites, these are all subterranean in habit. Included among them are the termites responsible for a great part of the termite damage of the world. Lists of the American species of this family appear on pages 145 and 147.

> *Family V.*—**Termitidae** Light, 1921. Fontanel present; mandibles never of *Leucotermes* or *Serritermes* type; anterior wing scale never large; wing only slightly reticulate, if at all; wing membrane and wing margin more or less hairy; pronotum of soldier and worker narrow, with uplifted median anterior lobe.

Here belong the vast majority of termites, 1,200 or more species in about 100 genera. They are confined almost entirely to the tropics, where they are dominant. All of the species of the family are ground-dwelling, but they exhibit a wide range of habits as regards food and structures of the colony. For the species of this family found in the United States see chapter 11.

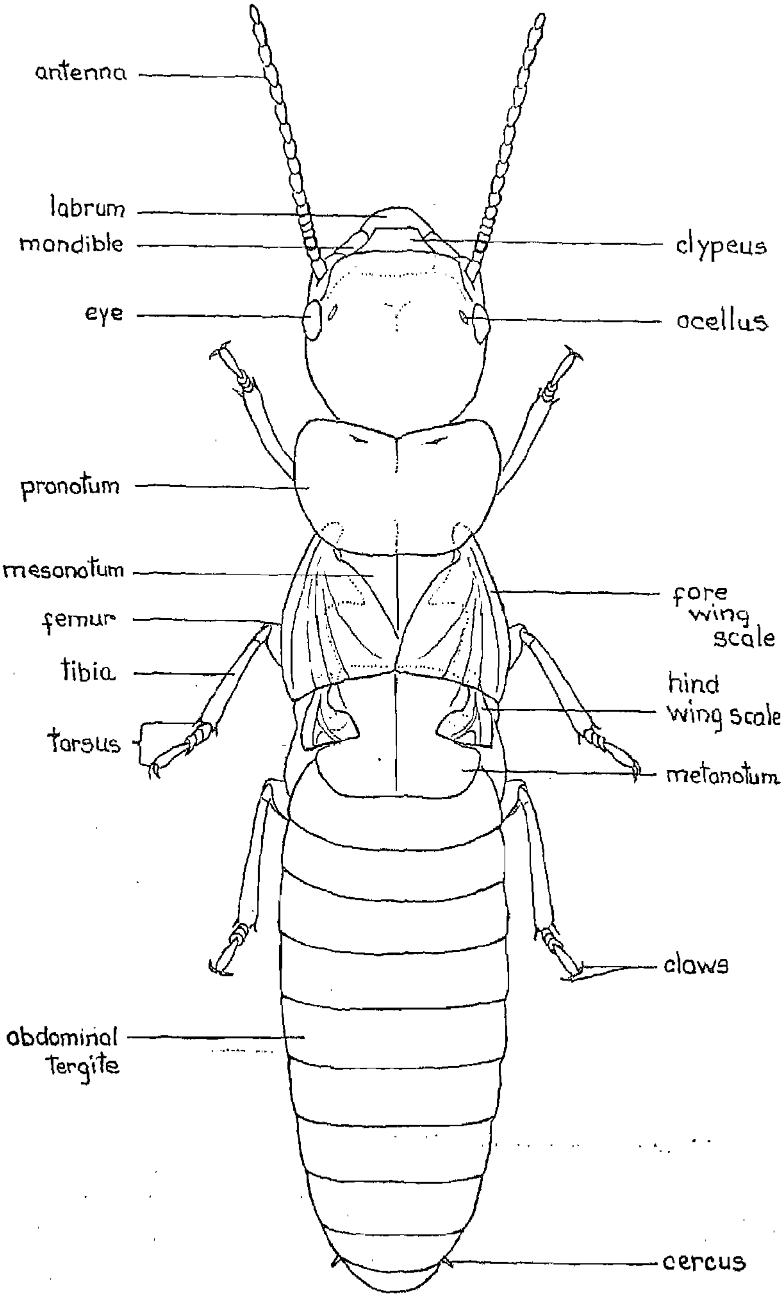

Fig. 27. Dealated female of *Kalotermes minor* showing those structures of a primary reproductive commonly referred to in descriptions and keys.

Perhaps the most fundamental difference between the Termitidae, on the one hand, and the other four families, on the other, is the absence in the Termitidae of the Protozoa which crowd the hind-intestine of the species of the lower families, and seem to be necessary for the utilization of wood by them (Cleveland, 1924). Seemingly correlated with this absence of great numbers of Protozoa are differences in food habits. The Termitidae are rarely

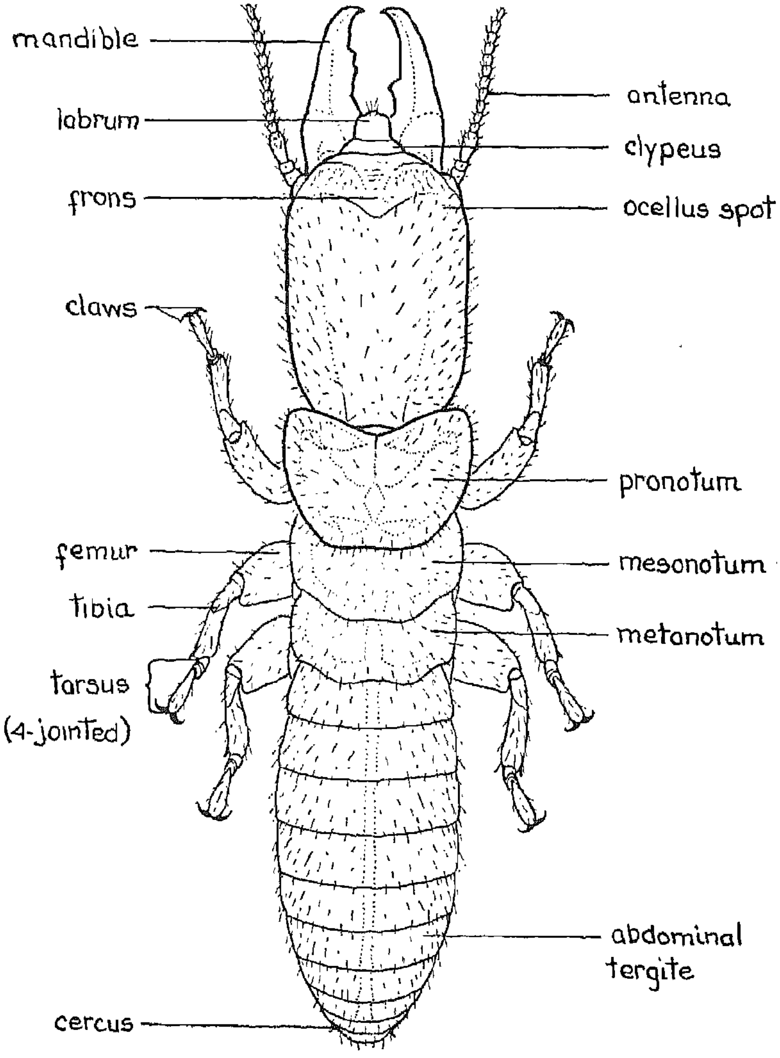

Fig. 28. Soldier of *Kalotermes minor* showing structures commonly mentioned in descriptions and keys.

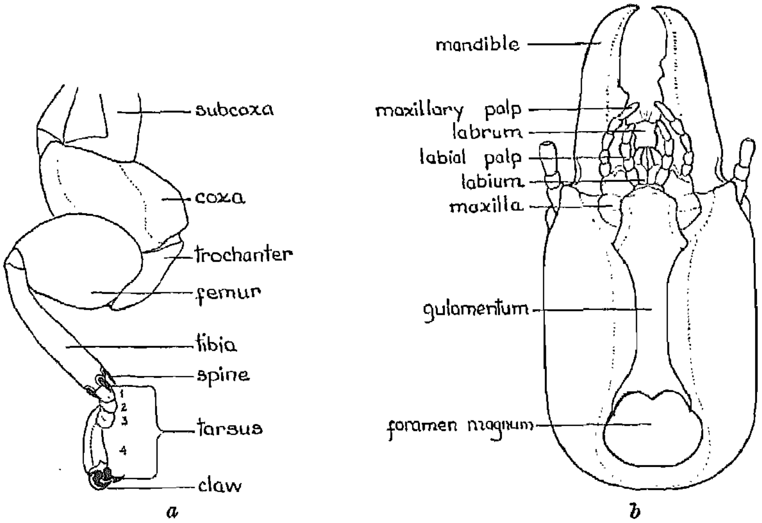

Fig. 29. *a*. Hind leg of soldier of *Kalotermes minor*, posterior surface. *b*. Head of soldier of *Kalotermes minor* in ventral view.

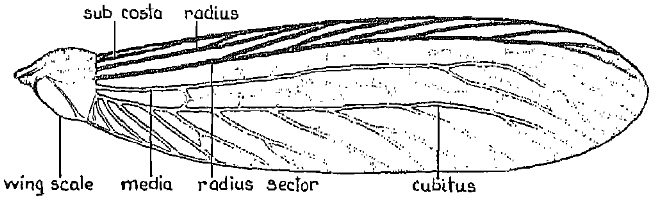

Fig. 30. Right fore wing of *Kalotermes minor*, with names of main veins.

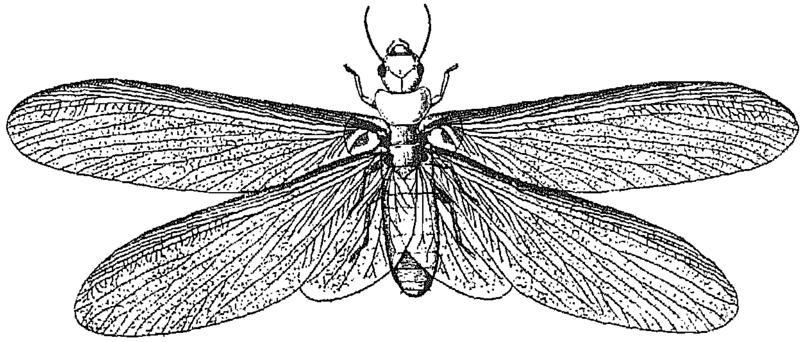

Fig. 31. Alate of *Mastotermes darwiniensis*, a primitive termite of northern Australia. From Silvestri (1909). Note the large lobe (anal lobe) at base of the posterior wings. This indicates relationship to cockroaches.

found feeding on sound wood, but utilize largely decayed or weathered wood, fungus, dead and partly decayed leaves, grass, organic detritus, leaf mold, etc.

One large group, including the mound-building termites of Africa and the Orient, build special gardens (fig. 32) of comminuted wood on which they grow fungus. A few others feed on decaying leaves and, contrary to the habits of most termites, forage in the forest, coming out in the daytime in armies consisting of a few files of workers going in each direction, with an outer protecting line of soldiers on either side. These armies have been estimated to consist of millions of individuals. Most termite workers are poorly protected

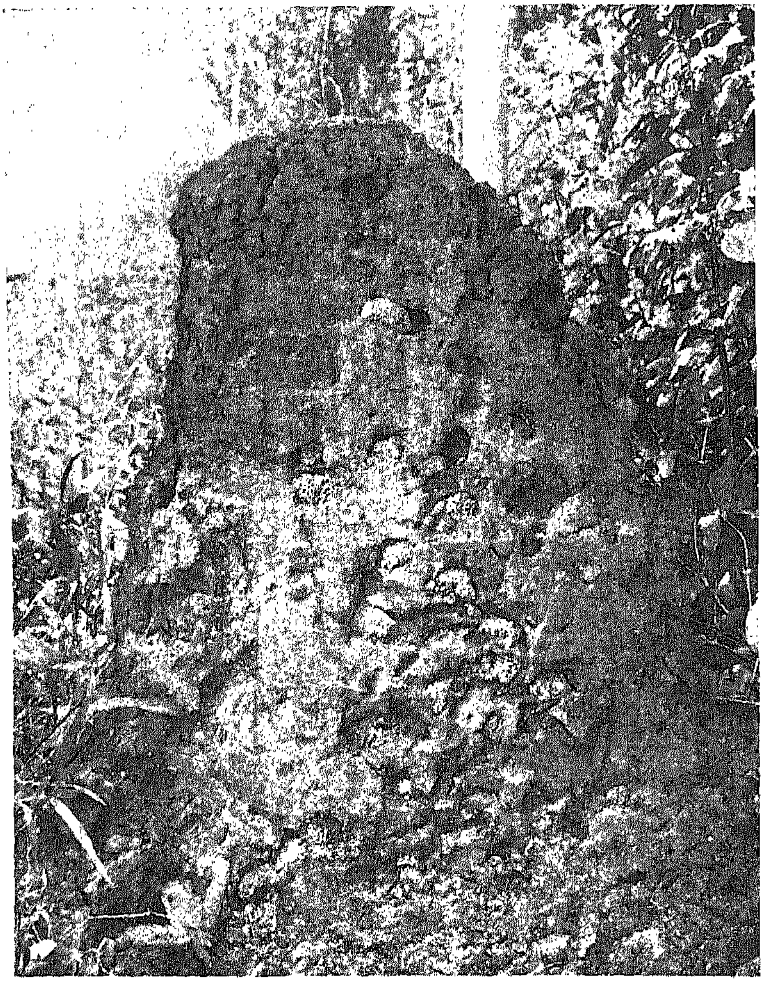

Fig. 32. Photograph of a mound of the Philippine mound-building termite, *Macrotermes gilvus*, cut open to expose the sponge-like fungus gardens. Photo by Philippine Bureau of Science.

with thin, light-colored chitinous exoskeletons, but these foraging species, as might be expected, have thick, dark-colored exoskeletons. Further, they have long, slender legs and are agile in their movements. For these reasons they are commonly mistaken for true ants.

Most of the species which forage in the daytime, together with hundreds of others which do not, belong to that subfamily of termites (*Nasutitermitinae*) in which the soldier has lost all but vestiges of its mandibles and is specialized for chemical warfare, its head being drawn out into a long nasus or rostrum, at the end of which is the opening to the cephalic gland (p. 32 and fig. 5*f*–*k*). This gland secretes a substance useful in defense because of its physical and chemical nature.

Most of the species of the family Termitidae, like those of the family Rhinotermitidae, construct covered runways of earth or comminuted or partly digested wood, to reach desirable wood above ground. Many species, particularly those of the subfamily Nasutitermitinae, build their colonial dwellings above ground in the form of so-called carton nests (pp. 136–137 and figs. 37, 25*c*), in which are located the royal pair and the young. A few of the species of the family Termitidae are of economic importance. However, the general trend of the family away from the use of sound wood renders it, in spite of wealth of species and habit types, relatively unimportant economically as compared to the other families of termites.

CHAPTER 11

THE TERMITE FAUNA OF NORTH AMERICA WITH SPECIAL REFERENCE TO THE UNITED STATES

BY

S. F. LIGHT

I. HISTORICAL BACKGROUND

American termites were little studied during the nineteenth century. A few species were early described by European writers (Kollar, 1837; Burmeister, 1839; Walker, 1853). Several others, including three of the common Pacific Coast species, were described by Dr. H. Hagen, for many years (1867–1890) at the Museum of Comparative Zoology at Harvard, whose *Monographie der Termiten* (1855–1860) was long the standard work on termites. In 1915 appeared the first important paper on biology and economics, by Dr. T. E. Snyder, of the U. S. Bureau of Entomology, who has since made many contributions.

There was no attempt at a comprehensive treatment of the termites of North America previous to the publication in 1920 of Bulletin 108 of the U. S. National Museum by Banks and Snyder, *A Revision of the Nearctic Termites* (Banks) with *Notes on Biology and Geographic Distribution* (Snyder). The studies of the Termite Investigations Committee have emphasized the imperative need of a careful authoritative revision of the American termites. As a part of the work of the Termite Investigations Committee, or as an outcome thereof, such a revision has been accomplished for the groups represented in the Pacific Coast area. Technical papers directed to this end are listed below.

EMERSON, ALFRED E.

1933. A revision of the genera of fossil and recent Termopsinae (Isoptera). Univ. Calif. Publ. Ent., 6:165–196.

LIGHT, S. F.

1930. The California species of the genus *Amitermes* Silvestri (Isoptera). *Ibid.*, 5:173–214.

1930. The Mexican species of *Amitermes* Silvestri (Isoptera). *Ibid.*, 5:215–232.

1932. Contributions toward a revision of the American species of *Amitermes* Silvestri. *Ibid.*, 5:355–414.

1933. Termites of western Mexico. *Ibid.*, 6:79–164.

—— Contributions to the taxonomy and biology of *Paraneotermes simplicicornis* (Banks). *Ibid.*, in press.

PICKENS, A. L.

1934. The distribution, biology, and life cycle of Pacific Coast species of *Reticulitermes*. *Ibid.*, in press.

SUMNER, ETHEL C.

1933. The species of the termite genus *Zootermopsis* Emerson (= *Termopsis* Hagen). *Ibid.*, 6(7):197–230.

II. GEOGRAPHICAL GROUPS IN THE TERMITE FAUNA OF NORTH AMERICA

The termite fauna of North America is varied, as might be expected in a region extending from the north temperate zone well into the tropical, and presenting a wide range of types of habitats. Much remains to be learned of its more southern elements, but the fauna as a whole seems clearly to consist of five rather distinct elements, chief among which is the holarctic genus *Reticulitermes*, with numerous species, present over practically the whole of the United States, and extending into British Columbia on the northwest and into Mexico along the central plateau. A second interesting element is the genus *Zootermopsis*, with three species. These are large, damp-wood termites confined to the Pacific Coast area exclusive of the mainland of Mexico. A third element, and an important one, is a group of wood-dwelling species belonging to the genus *Kalotermes*, chiefly tropical and subtropical, and therefore confined largely to the southern seaboard and border states, so far as the United States is concerned. The fourth and fifth elements are more heterogeneous. The fourth includes the three genera *Heterotermes*, *Amitermes*, and *Anoplotermes*, all ground-dwelling types and predominantly present in the desert or, at least, the arid areas of the subtropical and tropical regions. In the United States these genera appear only in the narrow southwestern desert fringe. The fifth element is a heterogeneous assemblage of genera, *Coptotermes*, *Nasutitermes* s. lat., *Hoplotermes*, *Mirotermes*, and *Microcerotermes*, all of which are ground-dwellers and essentially tropical in distribution, being particularly abundant in the damp tropics, but some of which extend their range into the semi-arid portions of Mexico, chiefly the central and southern portions. Of these but two or three species, of the genus *Nasutitermes* s. lat., enter the United States in southern Arizona, New Mexico, and Texas. As will be seen in the discussion below of habit types of termites (p. 306), relatively few of the species of this fifth group are of known economic significance. This group, however, includes the very destructive *Coptotermes crassus*.

III. TERMITES OF CALIFORNIA

California has nineteen species of termites. These, however, really represent two separate faunas with one intermediate species. The fauna of the coastal and moist mountain areas consists of four species: *Zootermopsis angusticollis*, *Z. nevadensis*, *Kalotermes minor*, and *Reticulitermes hesperus*. The desert fauna consists of fourteen species, as listed below:

Kalotermes (Kalotermes) hubbardi Banks
Paraneotermes simplicicornis Banks

Heterotermes aureus Snyder
Amitermes (Gnathamitermes) acutus Light
Amitermes (G.) fuscus Light
Amitermes (G.) infumatus Light
Amitermes (G.) magnoculus Light
Amitermes (G.) perplexus Banks
Amitermes (Amitermes) coachellae Light
Amitermes (A.) emersoni Light
Amitermes (A.) minimus Light
Amitermes (A.) silvestrianus Light
Amitermes (A.) snyderi Light
Amitermes (A.) wheeleri Desneux

R. tibialis is a barren-lands species which replaces *R. hesperus* in many arid and semi-arid sections of the state, being itself replaced by *Heterotermes aureus* in the southern desert.

This desert fauna constitutes an extreme northern and western segment of the desert and barren-lands fauna characteristic of Arizona, New Mexico, Texas, and northern Mexico, and is imperfectly known at present. *Kalotermes hubbardi* is placed here, although not as yet found in the desert proper in California except at one point on the California bank of the Colorado River. Some of the California species, *Amitermes wheeleri* and *A. minimus,* for example, have a range extending across the continent to southeastern Texas. *A. wheeleri* is found also as far south as Colima in the tropical coastal region of Mexico. *K. hubbardi* is found as far south as Colima on the mainland, to the tip of Lower California, and on the islands off the mainland and off Lower California, including Guadalupe Island.

The termite fauna of Mexico is discussed in detail on pages 306–311. Very little was known of it previous to the studies made by the Termite Investigations Committee (Light, 1933). The fauna of northwestern Mexico in Sonora and northern Sinaloa was found to be practically the same as that of Arizona and southeastern California, while southern Sinaloa, Nayarit, and Colima show increasingly important tropical elements, as brought out in the lists of Mexican species (chap. 28).

IV. TERMITES OF THE UNITED STATES

The termite fauna of the United States itself is unusually large for a nontropical region. It includes fifty-five species listed on pages 121–123, while Europe, for example, has but two. This fauna owes its richness to several factors: (1) the extensive speciation of the genus *Reticulitermes,* which is confined to the northern hemisphere and of which there are eight or more species in the United States; (2) the especially favorable climatic conditions on the Pacific Coast, where ocean currents induce a mild climate far into the north; and (3) the intrusion into the southern border and coastal states of an extensive series of species, some of them truly tropical, but more of them representative of the semi-tropical arid-lands fauna characteristic of the great Mexican plateau.

It cannot be too strongly emphasized that all of the termites doing extensive damage in the United States and, indeed, all except one, or possibly two, of the fifty-five species known to occur in the United States, are native species. We are not facing, therefore, any sudden invasion of new forms, as many have imagined, but simply an adjustment with species present for millions of years before man entered upon the scene. The two supposedly introduced species have very restricted ranges within the United States. _Reticulitermes lucifugus,_ the European subterranean termite, is found only in the vicinity of Forest Hills, Massachusetts, and _Cryptotermes brevis,_ the common powder-post termite, of wide distribution in the West Indies, Mexico, and Central and South America, has been found in four localities in southern Florida and in one in extreme southern Louisana.

A list follows of the termites known to occur in the United States, arranged in systematic order. After each is an alphabetical list of the states in which it is known to occur. Those termites which are of major economic importance are double starred (**) ; others of economic importance are single starred (*).

A SYSTEMATIC LIST OF THE TERMITES OF THE UNITED STATES WITH THEIR DISTRIBUTION BY STATES

Family Kalotermitidae

1. *_Zootermopsis angusticollis_ Hagen
   California, Idaho, Oregon, Washington (also British Columbia and Lower California)
2. _Zootermopsis laticeps_ Banks
   Arizona, New Mexico
3. *_Zootermopsis nevadensis_ Hagen
   California, Idaho, Montana, Nevada, Oregon, Washington (also British Columbia and, possibly, Lower California)
4. *_Kalotermes (Kalotermes) approximatus_ Snyder
   Florida, Louisana, Virginia
5. _Kalotermes (Kalotermes) arizonensis_ Snyder
   Arizona
6. _Kalotermes (Kalotermes) banksi_ Snyder
   Arizona
7. **_Kalotermes (Kalotermes) hubbardi_ Banks
   Arizona, California (also Mexico)
8. _Kalotermes (Kalotermes) jouteli_ Banks
   Florida (also Mexico)
9. _Kalotermes (Kalotermes) lighti_ Snyder
   Arizona
10. **_Kalotermes (Kalotermes) minor_ Hagen
    Arizona, California (also Mexico)
11. _Kalotermes (Kalotermes) minor_ form _varius_ Snyder
    Arizona
12. _Kalotermes (Kalotermes) occidentis_ Walker
    Arizona (also Mexico)
13. _Kalotermes (Kalotermes) schwarzi_ Banks
    Florida (also Mexico and the West Indies)
14. **_Kalotermes (Kalotermes) snyderi_ Light
    (= _Kalotermes marginipennis_ Banks)
    Florida, Georgia, Louisana, Mississippi, South Carolina, Texas (also Mexico and Central America)
15. _Kalotermes (Kalotermes) texanus_ Banks
    Texas
16. _Kalotermes (Neotermes) angustoculus_ Snyder
    Florida
17. _Kalotermes (Neotermes) castaneus_ Burmeister
    Florida (also the West Indies)

18. *Kalotermes (Calcaritermes) nearcticus* Snyder
Florida
19. **Paraneotermes simplicicornis* Banks
Arizona, California, Nevada, Texas (also Mexico)
20. ***Cryptotermes brevis* Walker
Florida, Louisana (also Mexico, the West Indies, and South America)
21. *Cryptotermes cavifrons* Banks
Florida

Family Rhinotermitidae

22. *Prorhinotermes simplex* Hagen
Florida (also the West Indies)
23. ***Heterotermes aureus* Snyder
Arizona, California (also Mexico)
24. *Reticulitermes arenincola* Goellner
Indiana, Michigan
25. **Reticulitermes claripennis* Banks
Arizona, Kansas, Texas (also Mexico)
26. ***Reticulitermes flavipes* Kollar
Alabama, Arkansas, Connecticut, Delaware, District of Columbia, Florida, Georgia, Indiana, Illinois, Kentucky, Louisiana, Maine, Maryland, Massachusetts, Michigan, Mississippi, Missouri, Nebraska, New Hampshire, New Jersey, New York, Ohio, Oklahoma, Pennsylvania, Rhode Island, South Carolina, Tennessee, Texas, Virginia, West Virginia, Wisconsin (also Mexico)
27. **Reticulitermes hageni* Banks
District of Columbia, Florida, Illinois, Indiana, Maryland, South Carolina, Texas, Virginia (also Mexico)
28. ***Reticulitermes hesperus* Banks
California, Idaho, Nevada, Oregon, Washington (also British Columbia)
29. **Reticulitermes humilis* Banks
Arizona, New Mexico (also Mexico)
30. ***Reticulitermes lucifugus* Rossi (The European species)
Massachusetts
31. **Reticulitermes tibialis* Banks
Arizona, Arkansas, California, Colorado, Idaho, Illinois, Indiana, Iowa, Michigan, Montana, Nebraska, Nevada, New Mexico, Oklahoma, Texas, Utah (also Lower California)
32. *Reticulitermes tumiceps* Banks
Arizona, Utah
33. **Reticulitermes virginicus* Banks
Arkansas, District of Columbia, Florida, Georgia, Illinois, Indiana, Kentucky, Louisiana, Maryland, Mississippi, Missouri, North Carolina, South Carolina, Tennessee, Texas, Virginia, West Virginia
Reticulitermes sp.
Minnesota, Wyoming

Family Termitidae

34. *Nasutitermes (Nasutitermes) costaricensis* Holmgren
Texas (also Porto Rico and Central and South America) [doubtful record]
35. *Nasutitermes (Nasutitermes) cinereus* Buckley
Texas (also Mexico)
36. *Nasutitermes (Tenuirostritermes) tenuirostris* Desneux
Arizona, Texas (also Mexico)
37. *Anoplotermes fumosus* Hagen
Arizona, Texas (also Mexico)
38. *Amitermes (Amitermes) coachellae* Light
Arizona, California, Nevada
39. *Amitermes (Amitermes) emersoni* Light
California
40. *Amitermes (Amitermes) minimus* Light
Arizona, California, Nevada, Texas
41. *Amitermes (Amitermes) pallidus* Light
Arizona
42. *Amitermes (Amitermes) parvipunctus* Light
Texas
43. *Amitermes (Amitermes) parvulus* Light
Arizona

44. *Amitermes (Amitermes) silvestrianus* Light
    California
45. *Amitermes (Amitermes) snyderi* Light
    California
46. *Amitermes (Amitermes) spadix* Light
    Texas
47. **Amitermes (Amitermes) wheeleri* Desneux
    Arizona, California, Nevada, Texas (also Mexico)
48. *Amitermes (Gnathamitermes) acrognathus* Light
    Texas
49. *Amitermes (Gnathamitermes) acutus* Light
    Arizona, California, Nevada
50. *Amitermes (Gnathamitermes) confusus* Banks
    Arizona, Texas
51. *Amitermes (Gnathamitermes) fuscus* Light
    California
52. *Amitermes (Gnathamitermes) infumatus* Light
    California (also Mexico)
53. *Amitermes (Gnathamitermes) magnoculus* Light
    California
54. *Amitermes (Gnathamitermes) perplexus* Banks
    Arizona, California, Texas
55. *Amitermes (Gnathamitermes) tubiformans* Buckley
    Texas

LISTS OF THE TERMITES FOUND IN EACH STATE

ALABAMA

1. *Reticulitermes flavipes* Kollar

ARIZONA

1. *Zootermopsis laticeps* Banks
2. *Kalotermes (Kalotermes) arizonensis* Snyder
3. *Kalotermes (Kalotermes) banksi* Snyder
4. *Kalotermes (Kalotermes) hubbardi* Banks
5. *Kalotermes (Kalotermes) lighti* Snyder
6. *Kalotermes (Kalotermes) minor* Hagen
7. *Kalotermes (Kalotermes) minor* form *varius* Snyder
8. *Kalotermes (Kalotermes) occidentis* Walker
9. *Paraneotermes simplicicornis* Banks
10. *Heterotermes aureus* Snyder
11. *Reticulitermes claripennis* Banks
12. *Reticulitermes humilis* Banks
13. *Reticulitermes tibialis* Banks
14. *Reticulitermes tumiceps* Banks
15. *Nasutitermes (Tenuirostritermes) tenuirostris* Desneux
16. *Anoplotermes fumosus* Hagen
17. *Amitermes (Amitermes) coachellae* Light
18. *Amitermes (Amitermes) minimus* Light
19. *Amitermes (Amitermes) pallidus* Light
20. *Amitermes (Amitermes) parvulus* Light
21. *Amitermes (Amitermes) wheeleri* Desneux
22. *Amitermes (Gnathamitermes) acutus* Light
23. *Amitermes (Gnathamitermes) confusus* Banks
24. *Amitermes (Gnathamitermes) perplexus* Banks
25. *Amitermes (Gnathamitermes) tubiformans* Buckley

ARKANSAS

1. *Reticulitermes flavipes* Kollar
2. *Reticulitermes tibialis* Banks
3. *Reticulitermes virginicus* Banks

CALIFORNIA

1. *Zootermopsis angusticollis* Hagen
2. *Zootermopsis nevadensis* Hagen
3. *Kalotermes (Kalotermes) hubbardi* Banks
4. *Kalotermes (Kalotermes) minor* Hagen
5. *Paraneotermes simplicicornis* Banks
6. *Heterotermes aureus* Snyder

7. *Reticulitermes hesperus* Banks
8. *Reticulitermes tibialis* Banks
9. *Amitermes (Amitermes) coachellae* Light
10. *Amitermes (Amitermes) emersoni* Light
11. *Amitermes (Amitermes) minimus* Light
12. *Amitermes (Amitermes) silvestrianus* Light
13. *Amitermes (Amitermes) snyderi* Light
14. *Amitermes (Amitermes) wheeleri* Desneux
15. *Amitermes (Gnathamitermes) acutus* Light
16. *Amitermes (Gnathamitermes) fuscus* Light
17. *Amitermes (Gnathamitermes) infumatus* Light
18. *Amitermes (Gnathamitermes) magnoculus* Light
19. *Amitermes (Gnathamitermes) perplexus* Banks

COLORADO

1. *Reticulitermes tibialis* Banks

CONNECTICUT

1. *Reticulitermes flavipes* Kollar

DELAWARE

1. *Reticulitermes flavipes* Kollar

DISTRICT OF COLUMBIA

1. *Reticulitermes flavipes* Kollar
2. *Reticulitermes hageni* Banks
3. *Reticulitermes virginicus* Banks

FLORIDA

1. *Kalotermes (Kalotermes) approximatus* Snyder
2. *Kalotermes (Kalotermes) jouteli* Banks
3. *Kalotermes (Kalotermes) schwarzi* Banks
4. *Kalotermes (Kalotermes) snyderi* Light
5. *Kalotermes (Neotermes) angustoculus* Snyder
6. *Kalotermes (Neotermes) castaneus* Burmeister
7. *Kalotermes (Calcaritermes) nearcticus* Snyder
8. *Cryptotermes brevis* Walker
9. *Cryptotermes cavifrons* Banks
10. *Prorhinotermes simplex* Hagen
11. *Reticulitermes flavipes* Kollar
12. *Reticulitermes hageni* Banks
13. *Reticulitermes virginicus* Banks

GEORGIA

1. *Kalotermes (Kalotermes) snyderi* Light
2. *Reticulitermes flavipes* Kollar
3. *Reticulitermes virginicus* Banks

IDAHO

1. *Zootermopsis angusticollis* Hagen
2. *Zootermopsis nevadensis* Hagen
3. *Reticulitermes hesperus* Banks
4. *Reticulitermes tibialis* Banks

ILLINOIS

1. *Reticulitermes flavipes* Kollar
2. *Reticulitermes hageni* Banks
3. *Reticulitermes tibialis* Banks
4. *Reticulitermes virginicus* Banks

INDIANA

1. *Reticulitermes arenincola* Goellner
2. *Reticulitermes flavipes* Kollar
3. *Reticulitermes hageni* Banks
4. *Reticulitermes tibialis* Banks
5. *Reticulitermes virginicus* Banks

IOWA

1. *Reticulitermes tibialis* Banks

KANSAS

1. *Reticulitermes claripennis* Banks
2. *Reticulitermes tibialis* Banks

KENTUCKY

1. *Reticulitermes flavipes* Kollar
2. *Reticulitermes virginicus* Banks

LOUISIANA

1. *Kalotermes (Kalotermes) approximatus* Snyder
2. *Kalotermes (Kalotermes) snyderi* Light
3. *Cryptotermes brevis* Walker
4. *Reticulitermes flavipes* Kollar
5. *Reticulitermes virginicus* Banks

MAINE

1. *Reticulitermes flavipes* Kollar

MARYLAND

1. *Reticulitermes flavipes* Kollar
2. *Reticulitermes hageni* Banks
3. *Reticulitermes virginicus* Banks

MASSACHUSETTES

1. *Reticulitermes flavipes* Kollar
2. *Reticulitermes lucifugus* Rossi

MICHIGAN

1. *Reticulitermes arenincola* Goellner
2. *Reticulitermes flavipes* Kollar
3. *Reticulitermes tibialis* Banks

MINNESOTA

1. *Reticulitermes* sp.

MISSISSIPPI

1. *Kalotermes (Kalotermes) snyderi* Light
2. *Reticulitermes flavipes* Kollar
3. *Reticulitermes virginicus* Banks

MISSOURI

1. *Reticulitermes flavipes* Kollar
2. *Reticulitermes virginicus* Banks

MONTANA

1. *Zootermopsis nevadensis* Hagen
2. *Reticulitermes tibialis* Banks

NEBRASKA

1. *Reticulitermes flavipes* Kollar
2. *Reticulitermes tibialis* Banks

NEVADA

1. *Zootermopsis nevadensis* Hagen
2. *Paraneotermes simplicicornis* Banks
3. *Reticulitermes hesperus* Banks
4. *Reticulitermes tibialis* Banks
5. *Amitermes (Amitermes) coachellae* Light
6. *Amitermes (Amitermes) minimus* Light
7. *Amitermes (Amitermes) wheeleri* Desneux
8. *Amitermes (Gnathamitermes) acutus* Light

NEW HAMPSHIRE

1. *Reticulitermes flavipes* Kollar

NEW JERSEY

1. *Reticulitermes flavipes* Kollar

NEW MEXICO

1. *Zootermopsis laticeps* Banks
2. *Reticulitermes tibialis* Banks
3. *Reticulitermes humilis* Banks

NEW YORK

1. *Reticulitermes flavipes* Kollar

NORTH CAROLINA

1. *Reticulitermes flavipes* Kollar
2. *Reticulitermes virginicus* Kollar

NORTH DAKOTA

None reported

OHIO

1. *Reticulitermes flavipes* Kollar

OKLAHOMA

1. *?Reticulitermes flavipes* Kollar
2. *Reticulitermes tibialis* Banks

OREGON

1. *Zootermopsis angusticollis* Hagen
2. *Zootermopsis nevadensis* Hagen
3. *Reticulitermes hesperus* Banks

PENNSYLVANIA

1. *Reticulitermes flavipes* Kollar

RHODE ISLAND

1. *Reticulitermes flavipes* Kollar

SOUTH CAROLINA

1. *Kalotermes (Kalotermes) snyderi* Light
2. *Reticulitermes flavipes* Kollar
3. *Reticulitermes hageni* Banks
4. *Reticulitermes virginicus* Banks

SOUTH DAKOTA

None reported

TENNESSEE

1. *Reticulitermes flavipes* Kollar
2. *Reticulitermes virginicus* Banks

TEXAS

1. *Kalotermes (Kalotermes) snyderi* Light
2. *Kalotermes (Kalotermes) texanus* Banks
3. *Paraneotermes simplicicornis* Banks
4. *Reticulitermes claripennis* Banks
5. *Reticulitermes flavipes* Kollar
6. *Reticulitermes hageni* Banks
7. *Reticulitermes tibialis* Banks
8. *Reticulitermes virginicus* Banks
9. *Nasutitermes costaricensis* Holmgren
10. *Nasutitermes (Tenuirostritermes) cinereus* Buckley
11. *Nasutitermes (Tenuirostritermes) tenuirostris* Desneux
12. *Anoplotermes fumosus* Hagen
13. *Amitermes (Amitermes) minimus* Light
14. *Amitermes (Amitermes) parvipunctus* Light
15. *Amitermes (Amitermes) spadix* Light
16. *Amitermes (Amitermes) wheeleri* Desneux
17. *Amitermes (Gnathamitermes) acrognathus* Light
18. *Amitermes (Gnathamitermes) confusus* Banks
19. *Amitermes (Gnathamitermes) perplexus* Banks
20. *Amitermes (Gnathamitermes) tubiformans* Buckley

UTAH

1. *Reticulitermes tibialis* Banks
2. *Reticulitermes tumiceps* Banks

VIRGINIA

1. *Kalotermes (Kalotermes) approximatus* Snyder
2. *Reticulitermes flavipes* Kollar
3. *Reticulitermes hageni* Banks
4. *Reticulitermes virginicus* Banks

WASHINGTON

1. *Zootermopsis angusticollis* Hagen
2. *Zootermopsis nevadensis* Hagen
3. *Kalotermes (Kalotermes) minor* Hagen (a single record)
4. *Reticulitermes hesperus* Banks

WEST VIRGINIA

1. *Reticulitermes flavipes* Kollar
2. *Reticulitermes virginicus* Banks

WISCONSIN

1. *Reticulitermes flavipes* Kollar

WYOMING

1. *Reticulitermes* sp.

CHAPTER 12

HABITAT AND HABIT TYPES OF TERMITES AND THEIR ECONOMIC SIGNIFICANCE

BY

S. F. LIGHT

The many different species of termites may be easily divided into a relatively small number of well defined groups if considered from the point of view of the places where they are to be found, *i. e.*, their habitats, and a few of their significant habits. These groups we shall speak of as habitat and habit types. The nature of the habitat and also of the habits it involves determine largely the economic problems to which the different termites give rise and the methods available for prevention and control. For example, all termites are either wood-dwelling or ground-dwelling. Colonies of wood-dwelling termites are confined entirely to wood (figs. 33*a*; 34*a–b*). The newly mated pair eats its way into wood at the time of swarming and the colony to which it gives rise remains in the wood throughout its existence, except when the winged reproductives swarm to found new colonies.

As the name implies, the colony of any ground-dwelling termite is located entirely in passages in the soil or partly in soil and partly in wood (fig. 33*b*). The termites united by this common habitat vary widely as regards habits of life. They differ as to food sources, location and method of initiation of the new colony, location of the reproductives, the structures they produce, and in many other ways. They all have in common, however, the habit and necessity of maintaining a permanent connection with the ground. The colony, residing partly or entirely within the ground, may extend its activities into wood directly (as in *A*, fig. 33*b*) or by constructing more or less exposed tubes or covered runways (*B*, fig. 33*b*), or it may even forage for its food in the open, as in the case of a few tropical species.

For practical purposes in economic discussions it has been found useful to subdivide these two major groups according to differences in habits, habitat, and distribution. Such differences give them varying economic importance and cause them to present widely varying problems of prevention and control.

The different habitat and habit groupings in the Pacific Coast area studied, and also some others including, roughly, all termites of known economic importance, are listed in the following outline. The systematic groups involved are also stated.

A. Wood-dwelling termites (largely of family Kalotermitidae).
   I. *Damp-wood termites:* (1) Genus *Zootermopsis.* (2) Genus *Prorhinotermes.* (3) *Paraneotermes simplicicornis.*

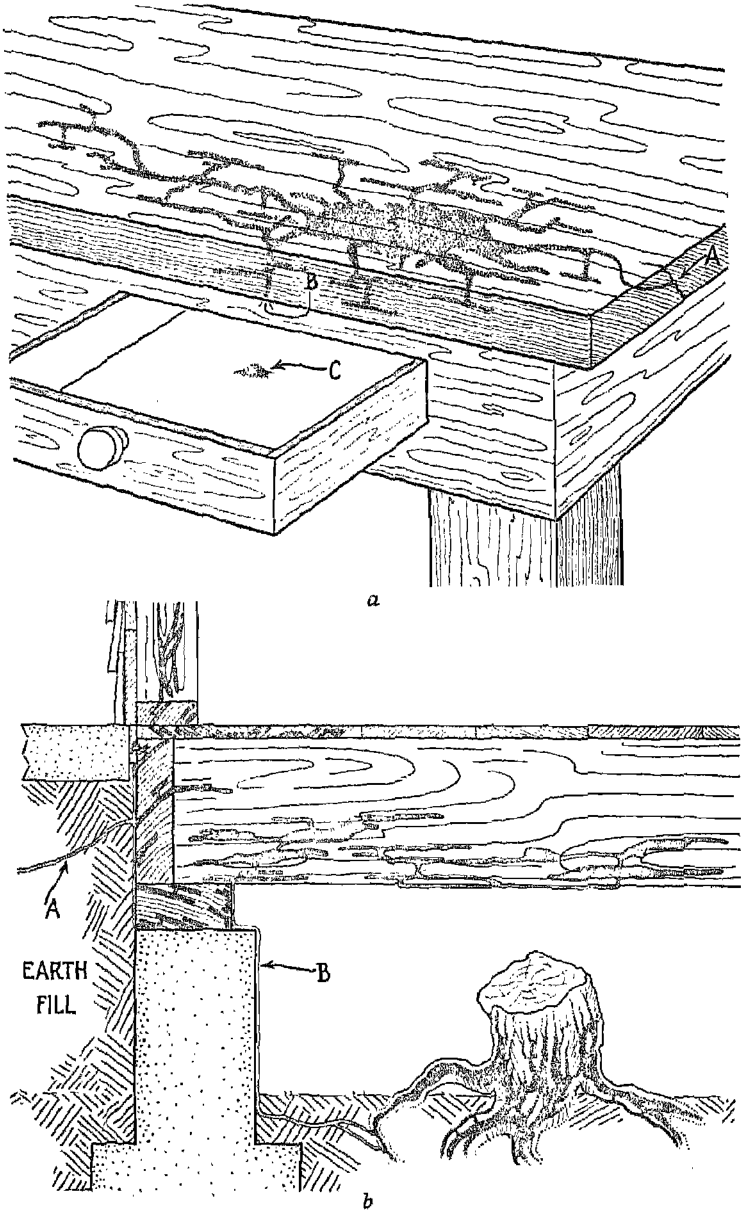

Fig. 33. *a.* Composite sketch showing schematically the workings of a powder-post termite *(Cryptotermes brevis)* in a table top. *A.* The assumed point of entry of the colonizing pair. *C.* A pile of tiny fecal pellets, indicative of the presence of these termites, thrown out at aperture *B.*

b. Sketch showing typical locations of galleries and workings of the western subterranean termite, *Reticulitermes hesperus. A.* Gallery in ground leading from main colony to unprotected woodwork in building. *B.* Covered runway from another colony located in a stump left under the house. This runway is built over concrete foundation to woodwork above, a less common condition.

- II. *Dry-wood termites:* The genus *Kalotermes* with its many subgenera. (1) *Powder-post termites,* subgenera *Cryptotermes, Calcaritermes,* etc. (2) *Dry-wood termites* proper, subgenus *Kalotermes.*

B. Earth-dwelling termites (families Rhinotermitidae and Termitidae).

- I. *Subterranean termites:* Genera *Coptotermes, Reticulitermes, Heterotermes* (=*Leucotermes*).
- II. *Desert termites:* Genera *Amitermes* in part and *Anoplotermes* in part.
- III. *Mound-building termites:* Chiefly fungus-growers of the genera *Macrotermes* and *Termes,* but certain species of other genera in various parts of the world, as *Coptotermes, Anoplotermes, Amitermes,* etc., have this habit.
- IV. *Carton-nest-building termites:* Many genera, notably those with nasute soldiers. (This does not include species of *Coptotermes,* which are included under subterranean termites.)

Needless to say, not all species in a large group of animals fit snugly into so small a number of habitat groups as we have designated. No doubt other groups will be characterized as similar studies are made in other regions, particularly in the tropics. For example, the interesting primitive monotypic family Mastotermitidae, and the genera and species of the family Hodotermitidae, and the foraging subgenera of *Nasutitermes* (*Hospitalitermes,* etc.) do not fit into these groupings. Various other gaps and overlappings in the tropic and subtropic groups occur at once to the mind of the student. So varied, for example, are the habits of the single genus *Coptotermes* that its species in different parts of the world fall into three different habitat groups. Certain species build earthen mounds (Australia); others build exposed carton nests (Africa); still others, while producing nests of similar materials, hide them underground (the Orient and America) and belong, therefore, in the subterranean habit type. Likewise, many genera and species of fungus growers do not build mounds, and many species of *Nasutitermes* do not produce external carton nests and hence would be considered subterranean termites, as here defined. Again, mounds are made by certain species of several other widely separated genera, such as *Anoplotermes* and *Amitermes,* whose species are usually subterranean, and by *Nasutitermes,* whose species are usually carton-nest builders.

Neither do all species and genera fit into the habit types into which by reason of their systematic position they would be expected to fall. *Paraneotermes simplicicornis,* our desert damp-wood termite, while closely related to the dry-wood termites, has habits quite different from those of most dry-wood termites and is really damp-wood and semi-subterranean in habit. These habitat and habit groups will be briefly discussed and defined here, and those of considerable economic importance in the area especially studied by the Termite Investigations Committee will be taken up again later in this report (chaps. 13–26).

Wood-Dwelling Termites

Damp-wood termites (chap. 24) typically enter the wood directly at the time of swarming and always confine their work to wood. They require a constant source of moisture and therefore are usually found in decaying wood. The group as heretofore defined by the Termite Investigations Committee in Circular 318 comprises the three species of large termites constitut-

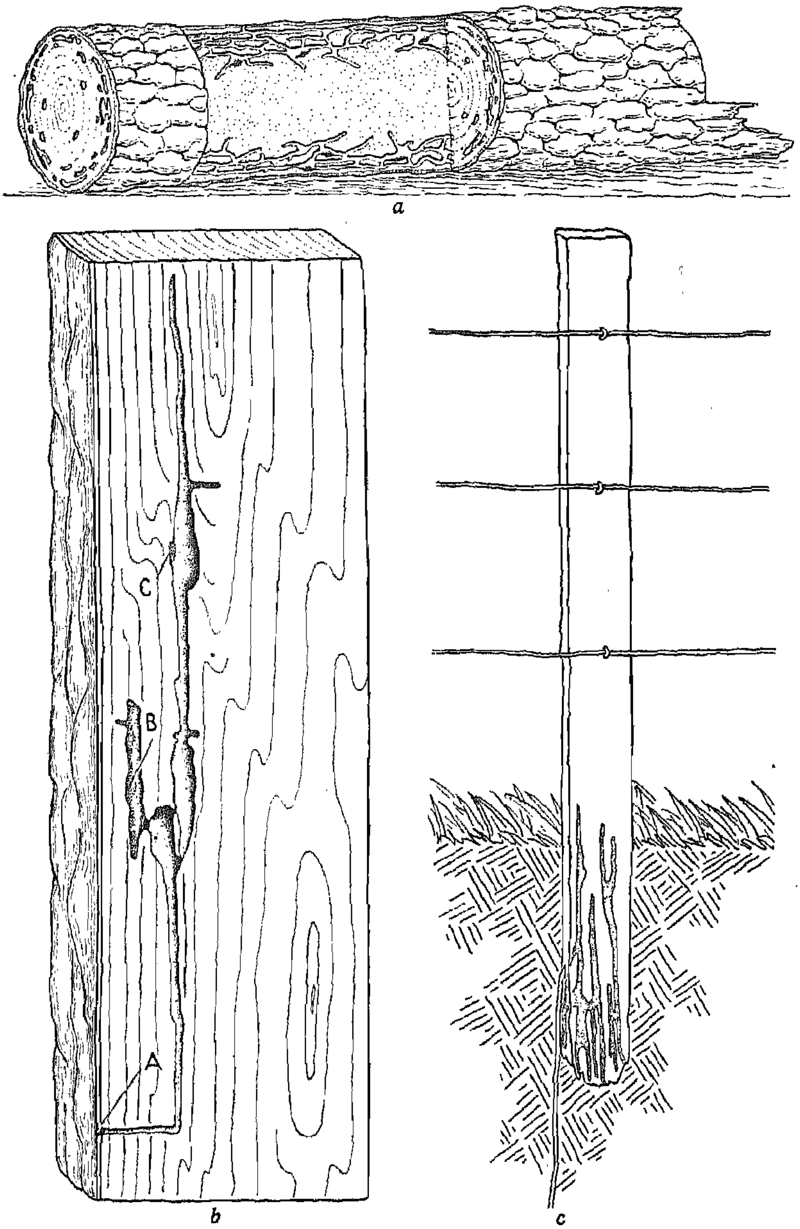

Fig. 34. *a.* Sketch showing the workings of a colony of damp-wood termites (*Zootermopsis*) in a pine log. Note that the colonizing pair entered above ground and that the workings are most extensive in the sapwood.

b. Sketch showing the entire dwelling of a young colony of the common dry-wood termite, *Kalotermes minor*. This represents the first two years' work of the developing colony. The piece of wood is erected in the figure. *A*. Point of entry of the colonizing pair, now plugged ing the genus *Zootermopsis* Emerson 1933 (=*Termopsis* Banks), particularly *Z. angusticollis* and *Z. nevadensis, Z. laticeps* being relatively rare. The genus is confined to western North America west of the Rocky Mountains. The two common species, although usually found in decaying wood, are quite capable of extending their activities into sound, and even into relatively dry wood (figs. 34*a*; 91). While they present a minor economic problem in most of the area concerned, they are occasionally responsible for serious attacks on wooden structures, usually in conjunction with fungus, particularly where there is a constant moisture supply, as in water tanks, piling, etc., or in wood in contact with damp ground. In certain areas of the Pacific Northwest their attacks on poles are reported to be of economic importance.

The species of the genus *Prorhinotermes* (family Rhinotermitidae), while systematically widely separated from *Zootermopsis,* fall into the damp-wood group on the basis of their habits, since the colonies are started in and confined to damp and, usually, decaying wood. Only one species of the genus, *P. simplex,* a native of the West Indies, occurs in the United States and there only in coastal Florida, where it is not known to be of economic importance. The Philippine species, *P. luzonensis,* has been found doing some damage to houses where water leaks furnished a constant moisture supply.

Paraneotermes simplicicornis (Banks), the desert damp-wood termite, was called the desert dry-wood termite before its habits were well known. It is common on the borders of the desert, along the washes and river valleys, and in the semi-arid portions of the southern border states and Mexico. Structurally it is related to the species of the subgenus *Neotermes,* but differs from all known species sufficiently to place it by itself in a genus, *Paraneotermes* Light *(in press).* It will be referred to hereafter as *Paraneotermes simplicicornis.* In its habits it differs widely from all known species of the family Kalotermitidae, which are all wood-dwelling and dry-wood termites. *P. simplicicornis* is restricted almost entirely to wood in the ground (fig. 34*c*), and therefore to damp wood and often to decaying wood. As will appear in the more complete discussion of this species below (p. 283), it is occasionally, if not typically, of semi-subterranean or temporary subterranean habit. It differs from the dry-wood termites in that its colonizing pairs cannot enter wood above the ground and in that its colonies are always located in wood which is partly or entirely buried; and from the subterranean termites in that it does not build covered runways to reach wood above the ground. It has seemed best, therefore, to consider it a damp-wood termite, since it presents the same economic problem so far as wooden structures are concerned. For an account of its peculiar attacks on young citrus trees see pages 288–290.

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up. *B.* Accumulations of pellets in an unused gallery sealed off from the main gallery. *C.* An accumulation of pellets in a recess of the main gallery.

c. The workings of the desert damp-wood termite, *Paraneotermes simplicicornis,* in the underground portion of a fence post. Note that these termites enter the wood from the ground, contrary to the habit of other damp-wood termites.

Sketches *a* and *c* diagrammatic; *b* based on dissection of workings of a single colony.

Dry-wood termites (chaps. 19–23) are wood-dwelling termites which characteristically enter and feed upon dry, sound wood and wholly confine their colonies to it (fig. 34*b*). In the broadest sense the group includes the entire genus *Kalotermes* Hagen, as well as other genera of the family Kalotermitidae. As might be expected in a large group of species inhabiting a great range of territory, they present a very considerable range of differences in habit and physical requirements. This is particularly noticeable with regard to the amount of moisture required. Certain tropical species, such as those of the subgenus *Cryptotermes*, are able to live indefinitely in dry, seasoned wood removed from all moisture contacts (fig. 33*a*). These have been designated *the powder-post termites because of the fine, sawdust-like piles of pellets* (fig. 33*a–c*) which they extrude from their workings. Here belong several other subgenera, *Lobitermes*, *Calcaritermes*, etc. The soldiers of all species of powder-post termites have *short, high, truncated heads (fig. 5d), functioning* to plug up runways in case of attack. Their mandibles are weak.

Other dry-wood termites, such as many species of the subgenus *Kalotermes*, while living in sound wood without much moisture, have been found by us to require at least 10 per cent moisture content for their continued existence. These are the dry-wood termites proper, responsible for the greater portion of damage by wood-dwelling termites, particularly outside of the tropics. The species of still another group, belonging chiefly to the subgenus *Neotermes*, require a larger and more constant supply of moisture. This they often get from the living tissues of plants, beginning their attacks in dead wood and extending them into the living areas. Such are the species which attack growing tea and coffee in Ceylon, teak trees in Java, and the ipil-ipil, guava, and other plants in the Philippines. Species of this group are not known to attack wooden structures to any extent.

EARTH-DWELLING TERMITES

Subterranean termites (chaps. 13–17).—The vast majority of the genera and species of termites, all, indeed, except the wood-dwelling termites, are actually ground-dwelling in habitat. Many, however, also have external nests or mounds, which serve to place them in separate groups. Those ground-dwelling termites which do not make exposed nests or mounds and are not otherwise segregated, as are the desert termites, are called subterranean termites. The economically important termites of this group are confined to three genera of the family Rhinotermitidae, *Coptotermes*, *Reticulitermes*, and *Heterotermes*. To these, therefore, the name subterranean termites in a strict sense has been confined. Actually, it happens that these species carry on a larger portion of their activities within wood than do the members of the higher family, the Termitidae. The latter, however, are not of great or widespread economic importance *and are largely included in the other groups* designated on the basis of some other habit character (pp. 136–137).

From the point of view of our inquiry, the subterranean termites proper *are the members of the three genera mentioned. They are accountable* for the major portion of economic loss due to termites throughout the world. They start new colonies either in the earth or in moist or decaying wood in or on the ground. The colony nearly always maintains a ground connection. Some colonies of *Coptotermes* furnished with a continuous supply of moisture have been found isolated from the ground. Extreme examples of such detachment from the soil are colonies of *Coptotermes* found in ships.

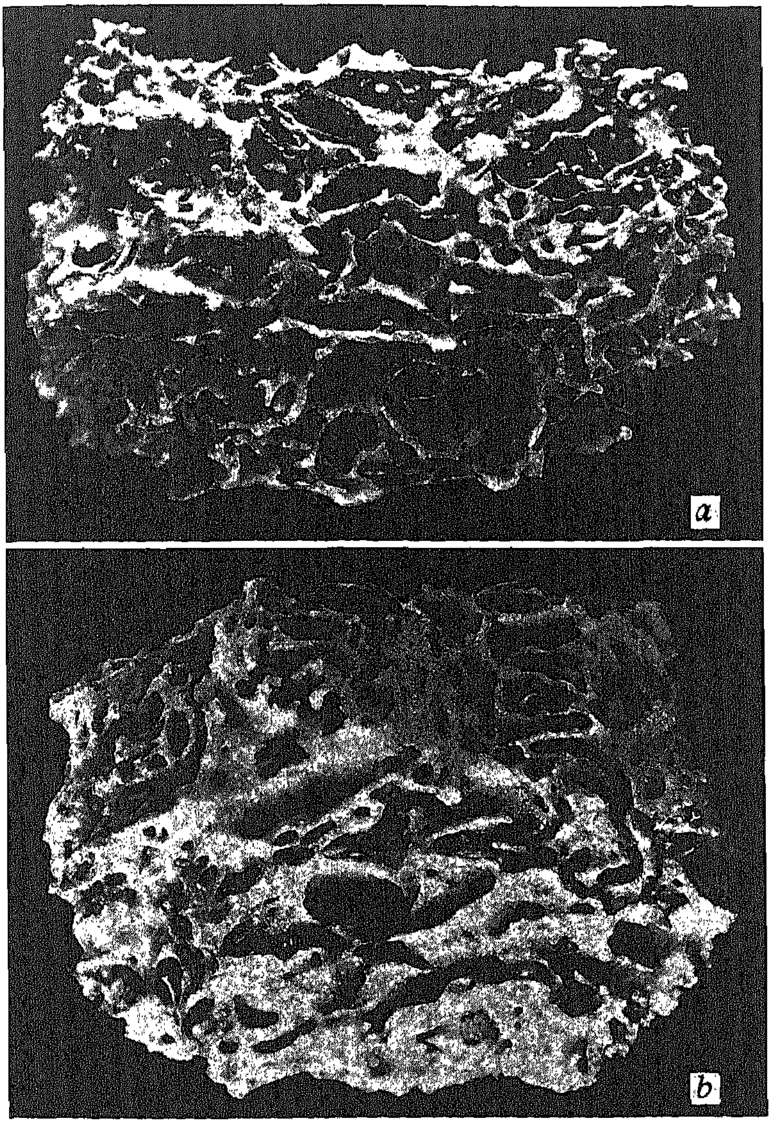


Fig. 35. Photograph of parts of the nest material of *Coptotermes vastator*, the Philippine subterranean termite. *a.* Near the center the chambers are large, and the nest a mere network. *b.* Toward the periphery the chambers are broad and very flat.

Part or practically all of the dwelling of the colony of the subterranean termite, including the royal cell, is located in the ground, in some cases in a nest of frass, semi-carton in nature (fig. 35). *Coptotermes* produces large nests of this type (fig. 41). Those of *Heterotermes* are less well developed, and those of *Reticulitermes* are mainly vestigial. Under certain conditions, however, several species of *Reticulitermes* have been found to build such structures (fig. 36).

Subterranean termites demand a constant upply of moisture, which they normally obtain from the ground. Whether or not the ground connection serves other important purposes, such as contact with molds and fungi, remains undetermined. Where wood is attacked away from the ground, covered runways are constructed between the nest in the ground and the workings in wood (*B*, fig. 33*b*; and fig. 48). These covered ways are composed of varying proportions of earth particles, wood fragments, fecal excretions, and perhaps also salivary secretions.

Desert termites (chap. 18).—The deserts and other arid and semi-arid areas of southwestern United States and large parts of Mexico are the home of numerous species of the genus *Amitermes* (family Termitidae). There they feed upon the woody parts of many desert plants and on casual wood of various kinds, particularly drift wood in dry washes. Species of the subgenus *Gnathamitermes* (chap. 18) attack only the thin outside layers of weathered wood and hence effect no significant structural damage. *A. tubiformans* causes damage to forage plants on occasion, and more rarely *A. perplexus* damages trees by building over and destroying considerable areas of bark, including the cambium. The species of the subgenus *Amitermes* (chap. 18) confine their attacks to wood in and on the ground, and, in all but two or three species, largely to the surface. They are not known to be of economic significance, but may become so locally with the agricultural development of desert areas. Two species, *A. wheeleri* Desneux (=*A. californicus* Banks) and *A. minimus* Light (= *A. wheeleri* Banks), do attack sound wood on occasion, doing some actual damage. They present the possibility of still greater potential damage.

In this group of desert termites may well be placed the species of the genus *Anoplotermes* found in the United States and some, at least, of the species found in Mexico. The species of this genus are the only termites lacking soldiers. They are not known to be of economic significance. One species of the genus *Anoplotermes* is a prolific builder of mounds in South America. Species of this genus are found in Central America and Mexico and one species, *A. fumosus* Hagen, is found in our southwestern border states. Those species of the genus found in Mexico and the United States may be grouped with the species of *Amitermes* as desert termites since they frequent the same arid or semi-arid areas, have much the same habits of life, and are even found under the same cowchip or piece of wood.

All these species, while ground-dwelling and without visible nest structures, have been separated from the subterranean termites proper. They are of little known economic importance, and they either do not build covered

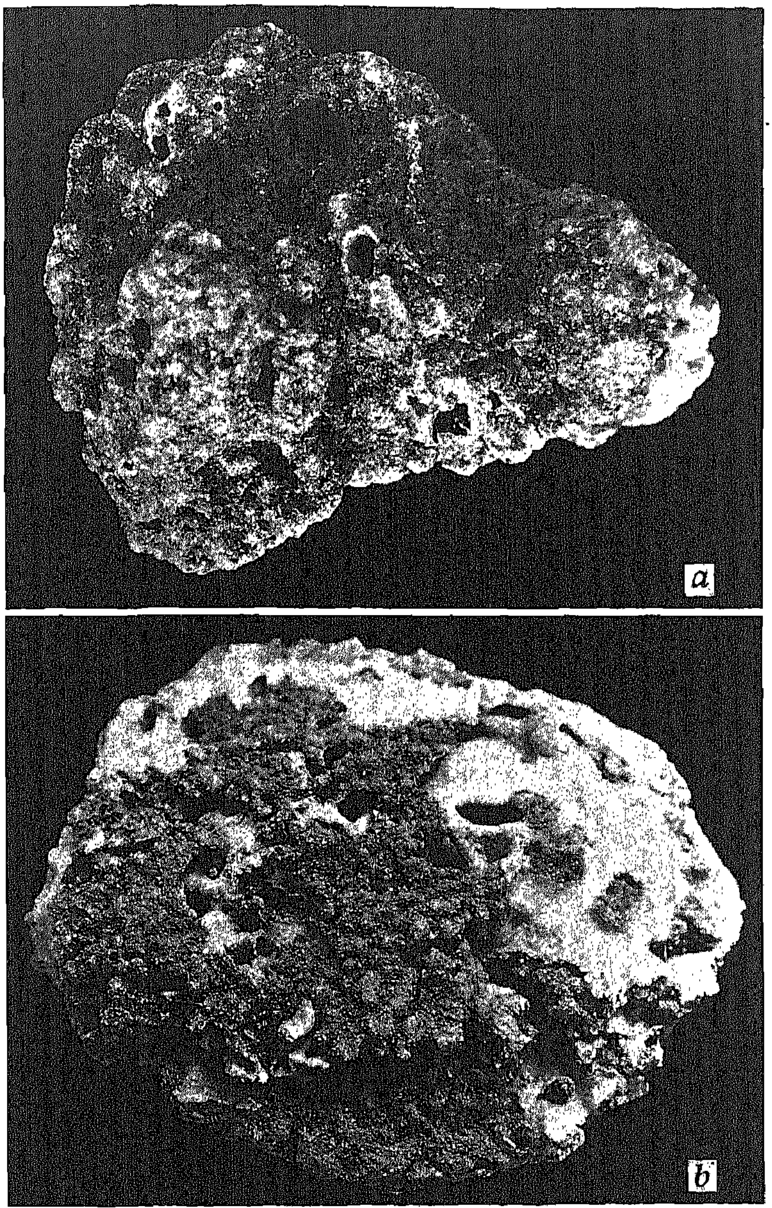


Fig. 36. Photographs of nests made by *Reticulitermes*. *a*. By an undetermined species in sawdust under a house in Memphis, Tennessee. Photograph by W. B. Hill. *b*. Similar structure produced by *R. hesperus* near furnace pipes under a house in Berkeley.

ways to reach the wood they attack or confine their attacks to the thin outer surface, and hence present a very different economic problem. These differences, combined with their limited geographical range, seem to justify the separation of the desert termites as a distinct habit group.

Mound-building termites.—Many species, belonging chiefly to several of the fungus-growing genera of the Termitidae, are known to build extensive mounds of comminuted earth cemented with salivary secretions. Most important in this respect is the genus *Macrotermes,* whose mounds form conspicuous elements of the landscape in Africa, the Philippines (fig. 32), the East Indies generally, and much of the tropical Asiatic mainland. The genus *Termes* (=*Odontotermes*) also includes species with this habit. As a rule, these species do not attack wooden structures, although in certain regions they present difficult and even insurmountable problems to the agriculturist because of the durability of the mounds they build. These two genera do not occur in the New World, but in parts of Central and South America species of *Anoplotermes, Amitermes, Cornitermes,* and other genera build conspicuous mounds (fig. 103*a*).

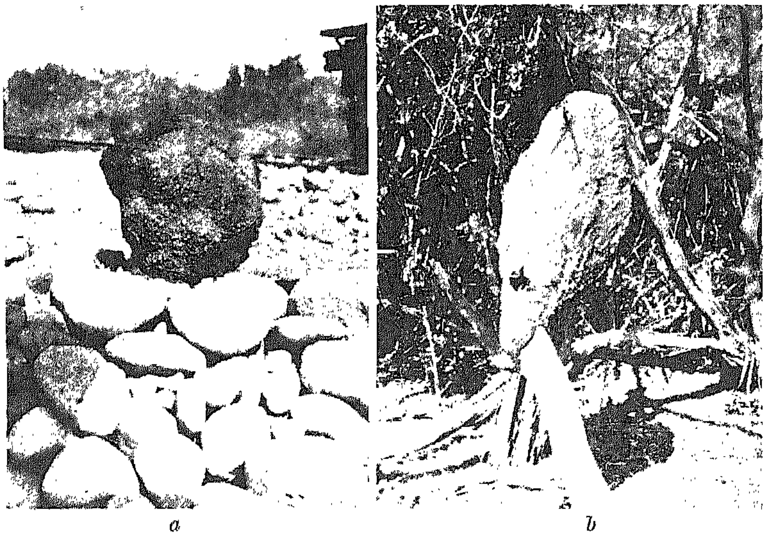


Fig. 37. Photographs of two carton nests of *Nasutitermes nigriceps,* the black Mexican nasute, taken by S. F. Light near Mazatlan, west coast of Mexico. *a.* Small round nest removed from tree. *b.* A larger nest in position in the forest, 8 feet above the ground.

Carton-nest-building termites.—The termites of this group of ground-dwellers, while maintaining a ground connection with ramifications of the colony within the earth, habitually construct one or more exposed nests of a paper-like material, known as carton, composed largely of fecal materials containing much lignin and other remnants of the wood passed through the intestine. Mingled with this at times and cemented by it are minute wood fragments, and in certain cases earthen materials. These nests vary widely as to shape, size, location, and materials, but are characteristically patterned in each of the widely separated genera and species which build them. Such nests are constructed by the species of many of the genera and subgenera of nasute termites (genus *Nasutitermes* s. lat.) and by some species of *Microcerotermes, Amitermes* and *Mirotermes*.

The nests of *Nasutitermes nigriceps* (Haldeman), the common black-headed nasute of Mexico (Light, 1933), are large, brown, oblong structures built around branches of trees or posts (fig. 37). They form a conspicuous element of the forest landscape in the semi-tropical areas of southwestern Mexico. The nests of other species, especially of *Nasutitermes cornigera* (fig. 103*b*), are common sights along the railways in Panama and elsewhere throughout the tropics. The mound-building and carton-nest-building termites, although a very common element of the termite fauna of Mexico (chap. 28), the Philippine Islands (chap. 31), Central America (chap. 30), and the West Indies (chap. 29), will not be further discussed here, since they are not of great economic importance and are not found in the United States.

ECONOMIC SIGNIFICANCE OF HABITAT GROUPS

The habitat groups discussed above emphasize four important points of difference in the life habits of various groups of termites. These definite biological characteristics define the widely varying economic problems presented by the different groups of termites, and it is only by clearly understanding and taking advantage of them that these problems are to be solved. These biological characteristics are stated below in the form of five questions which must be answered concerning the common species of a given locality before intelligent steps may be taken either to prevent termite damage in new construction or to repair it if already existing.

1. Do the colonizing pairs of the termites enter wood, or do they enter the earth, or at least wood in the earth?
2. Does the termite require wood with high moisture content, or does it thrive in relatively dry, sound wood?
3. Does the termite live entirely in wood, or does it live partly in the ground and require a ground connection?
4. Does the termite build covered runways to reach wood above the ground, or is it confined to wood in or on the ground?
5. Is the termite able to attack, and in the habit of attacking sound wood, or is it largely limited to decayed wood?

It is largely on the basis of these biological characteristics that all termites are divided into a relatively few habitat or habit types, as defined above. The set of statements given below is designed to bring out the essential biological significance of these groupings as bearing on their economic significance.

1. If the colonizing pair enter wood above ground at the time of swarming, the termite is a *wood-dwelling termite*.
2. If the colonizing pair enter the earth, or wood in the earth, the termite is a *ground-dwelling termite*.

3. If the termite colony is confined entirely to wood, the termite is a *wood-dwelling termite.*

4. If the termite colony is always partly in the ground or in connection with it, the termite is a *ground-dwelling termite.*

5. If the termite colony lives mainly in wood with high moisture content it is a *damp-wood termite.*

6. If the termite thrives in dry, sound wood it is a *dry-wood* or a *powder-post termite.*

7. If covered runways are built from the nest in the ground over intervening materials to reach wood elsewhere, the termite is an *earth-dwelling termite,* and may be a *subterranean termite* proper, a *mound-building termite,* a *carton-nest-building termite,* or a *desert termite* of the subgenus *Gnathamitermes* of the genus *Amitermes.*

8. If the termite builds covered ways but not mounds or exposed nests, and attacks the deeper layers of wood, it is a *subterranean termite* proper (genera *Reticulitermes, Coptotermes,* and *Heterotermes*).

9. If the termite is able to attack wood only in or on the ground, it is either one of the common desert termites constituting the subgenus *Amitermes,* or the desert damp-wood termite *Paraneotermes simplicicornis.*

Two fundamental methods are involved in preventing termite damage, as indicated in chapter 46: first, so to place materials as to prevent their being reached by the termites and, second, to use materials which are inedible either because distasteful or because poisonous. The second method is clearly the only one entirely feasible in combating those termites which are able to reach the upper parts of a structure on the wing and there to bore in and to start new colonies (fig. 38). Complete protection against this type of termite requires the use of treated materials or of materials naturally resistant to termites. In many parts of the tropics, as in Panama and western coastal Mexico, the extra cost involved in the use of such materials is justified by the protection afforded against damage. In these localities such protective measures have been estimated to add but 10 per cent to the cost of building. Further, in many parts of the tropics furniture is also subject to attack, chiefly by powder-post termites (fig. 33*a*), a condition which could be readily avoided by the proper treatment of the wood in the factory.

In most of the United States the expectation of damage from termites of the dry-wood type does not justify the cost of complete protection (fig. 59*b*), although in certain limited areas along the southern border such cost may be justified. Where this cost does not seem justified and where there is yet a possibility of attack from dry-wood termites, a certain amount of protection may be had by properly painting exposed surfaces and screening with fine mesh wire screen all windows and other openings near the roof. Attacks from all but dry-wood termites can be largely prevented by placing materials so as to avoid ground connection (chaps. 46, 48), or by using inedible or naturally resistant substances.

In the case of the damp-wood termites it suffices to raise the susceptible wood from ground contacts, thus eliminating the necessary moisture supply

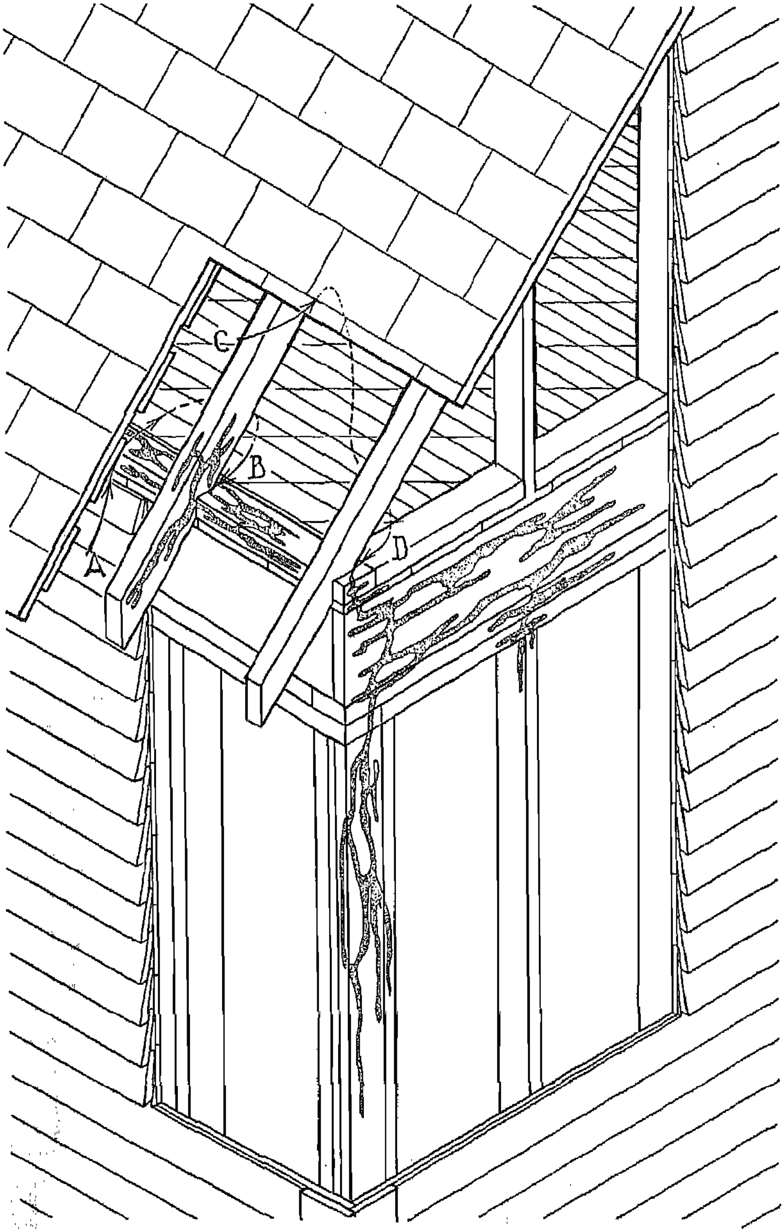


Fig. 38. Diagrammatic sketch showing workings of two colonies of the common dry-wood termite *Kalotermes minor*, based on numerous observations of colonies in houses. The lines *AB* and *CD* mark the assumed original routes of entry of the two colonizing pairs. The galleries of the two colonies are not connected with each other.

and with this the termites also, except in those situations where other moisture sources keep the wood continually damp and thus supply the necessary *milieu* for the founding and developing of colonies of this type, as in the case of water tanks or wood kept moist by leaking plumbing or steam pipes or by sweating. Marine structures above the water are peculiarly liable to condensation of moisture, which attracts attack by the damp-wood termite. In such locations improved ventilation and treated lumber offer a solution. The same method will suffice in the case of attacks by desert termites *(Amitermes)*, since the species of this group which do build covered ways (subgenus *Gnathamitermes*) confine their activities to the paper-thin, outer, weathered layer of the wood, and hence do no serious damage, while the species of the subgenus *Amitermes* do not build covered ways and hence are confined to wood in or on the ground. No instance is known in which the covered ways of *Gnathamitermes* have been built over any material other than wood, such as brick, stone, or concrete.

It will be noted in the case of damp-wood and most desert termites that, since we are not dealing with termites which build covered runways, we are not concerned with the height of the foundation used to raise the wood above ground level, but simply with the removal of the wood from ground contact, since this will eliminate moisture and therefore prevent attacks by those desert termites which are unable to build covered runways.

The prevention of damage by subterranean termites proper (*Reticulitermes, Heterotermes, Coptotermes*) constitutes the larger termite problem. Prevention can usually be accomplished by isolating the wood from ground contact, *i. e.*, by proper construction methods. The methods used must be adapted to the ability and propensity of the particular species in a given locality to build covered runways over the impenetrable foundations in order to reach susceptible materials above. As pointed out in other sections (pp. 549–550), a ground clearance of eighteen inches or more inside the foundation and six inches for outside walls (chaps. 46, 48) is sufficient to give protection against *Reticulitermes* under most conditions in most areas, since these termites rarely, if ever, build covered ways over a foundation in the open. The addition of a termite barrier will put an additional block in the way of the attack (p. 550). In desert areas where *Heterotermes* commonly builds up and over to reach wood above the ground, and in countries where *Coptotermes* is present, the use of both high foundations and the shield would seem to be indicated, and in addition the use of treated material for all wood in the substructure, so that even if tubes are built up to the wood, or if covered ways are built over the foundation, there is always encountered a surface either unpalatable or deterrent, or both.

This subject cannot be dropped without accentuating the great importance of *careful, competent inspection* of structures at regular and frequent intervals by the informed owner or by competent and trustworthy operators as a means of avoiding serious termite damage (chap. 47), since it is impossible to eliminate attacks entirely.

CHAPTER 13

AMERICAN SUBTERRANEAN TERMITES, THEIR CLASSIFICATION AND DISTRIBUTION

BY

S. F. LIGHT AND A. L. PICKENS

The American subterranean termites include species of all three of the genera properly included in this habitat group, *Reticulitermes*, *Heterotermes* (= *Leucotermes*) and *Coptotermes*. *Reticulitermes* is a northern hemisphere, temperate zone genus (fig. 39) with at least one species each in southern Europe and Asia (China and Japan) and nine in North America. *Heterotermes* and *Coptotermes* are found in all of the tropics, and species of one genus or the other, or both, extend into the subtropics in different parts of the world.

Each caste of the species of *Reticulitermes* resembles the same caste of *Heterotermes* in shape and size. The soldiers of *Heterotermes*, however, have much longer and much slenderer mandibles than those of *Reticulitermes* (fig. 40*a*–*d*), and the alates of *Heterotermes* are night-fliers and light colored, usually yellow to light brown, while those of *Reticulitermes* are dark, generally black, and usually fly during the middle of the day.

All castes of the species of *Coptotermes* are larger than those of *Reticulitermes* and *Heterotermes*. The head of the *Coptotermes* soldier is strikingly different, being egg-shaped, with a large, tubular, forward-directed fontanel located near its anterior end (fig. 5*b*), from which there is emitted a copious milky-white secretion of the cephalic gland, used especially for defense against ants. Because of this secretion *Coptotermes* are known in certain localities as "milk termites." The Protozoa of *Coptotermes* are much like those of *Heterotermes*, while those of *Reticulitermes* are strikingly different from either.

The genus *Coptotermes* is found throughout the tropics, and in certain regions its range extends through the subtropics well into the temperate zone, as in China and southern Japan. Its species are responsible for a very large part of the total termite damage in the tropics and the oriental subtropics. Here belong the most important economic species of Panama and Central America, *C. niger* Snyder and *C. crassus* Snyder (chap. 30); by far the most important economic species of the Philippines, *C. vastator* Light (chap. 31); and the oriental termite, *C. formosanus* Shiraki, the chief cause of termite damage in China, Formosa, and Hawaii (chap. 27). No species of the genus *Coptotermes* is known to occur in the United States, although there is always a possibility that the oriental termite may be introduced here from Hawaii, as it was introduced into Hawaii from the Orient. Whether it would be able to adjust itself to the climatic conditions of California is uncertain, although

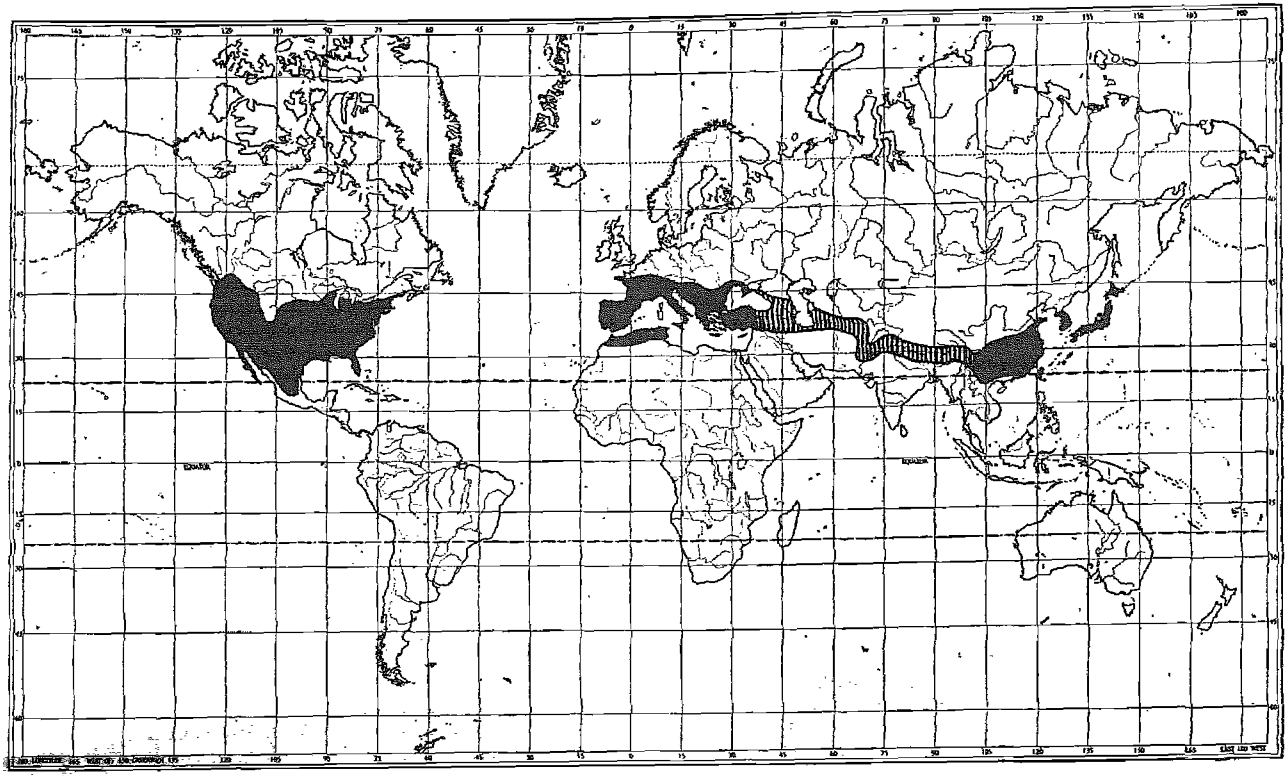


Fig. 39. Map showing world distribution of the genus *Reticulitermes*. Hatched areas are assumed; solid areas are based on the interpretation of published records.

the fact that it is found in southern Japan and on the Yangtze river in China indicates that it could do so as far north perhaps as San Francisco, especially in heated dwellings (pp. 18–20). The only species known to occur in North America is *C. crassus* Snyder, which has been found at Colima on the west coast of Mexico (Light, 1933).

The species of this genus are extremely active and destructive. They form large, rapidly developing colonies which build covered runways freely over other materials to reach wooden structures (figs. 95*a–b*; 41). Where present they form a real menace and an extremely difficult economic problem. Swarming at night and attracted strongly by lights, they alight in, and are readily transported by, automobiles, steamships and aeroplanes. Like other subterranean termites they ordinarily have a ground connection and live partly in ground and partly in wood. *Copotermes formosanus* has the ability, however, not known to be possessed by other subterranean termites, of living without ground connection where there is a suitably located constant water supply. A ship arriving in San Francisco from the tropics, for example, was found to contain a very large colony with probably hundreds of thousands of nymphs, workers and soldiers, and several supplementary reproductives, living in the heavy flooring and wainscoting of three cabins and centering under a leaking coffee percolator. Without such constant water supply, however, the colonies of this species cannot persist without ground connection.

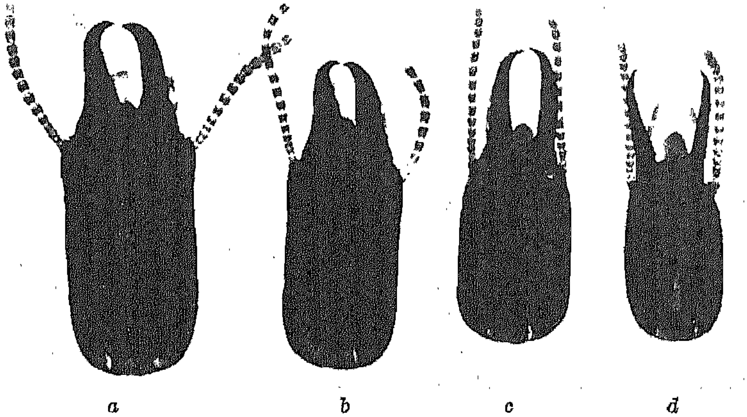


Fig. 40. Photographs of heads of soldiers of *Reticulitermes* and *Heterotermes*. Note that the mandibles of *Heterotermes* are relatively longer and more slender.

a. Reticulitermes hesperus, the western subterranean termite, from Berkeley, California. *b. Reticulitermes tibialis,* the barren-lands subterranean termite, from Stockton, California. *c. Heterotermes aureus,* the desert subterranean termite, from Indio, southeastern California. *d. Heterotermes intermedius,* the intermediate subterranean termite, from Guaymas, Sonora, Mexico.

The genus *Heterotermes* (= *Leucotermes*) has species in all tropical regions. Only one of the eleven American species, *H. aureus* Snyder, extends its range northward into the desert fringe of southwestern United States.

The species of *Heterotermes* are similar in habit to the oriental species of *Coptotermes,* and in certain regions they are of considerable economic importance. Particularly is this true in tropical and subtropical America, where they are responsible for a vast amount of damage. One species of this genus, *H. tenuis* Hagen, supposedly transported by ship (Dietz and Snyder, 1923), was introduced into the Island of St. Helena, where it is said to have done damage amounting to £60,000. Along the west coast of Mexico, as far south as Colima and as far inland as Jalisco, species of this genus were found to be responsible for widespread, extensive damage to houses, poles, etc. (chap. 28, and Light, 1933). The same condition no doubt continues through to Central America. In the United States *H. aureus* is accountable for considerable dam-

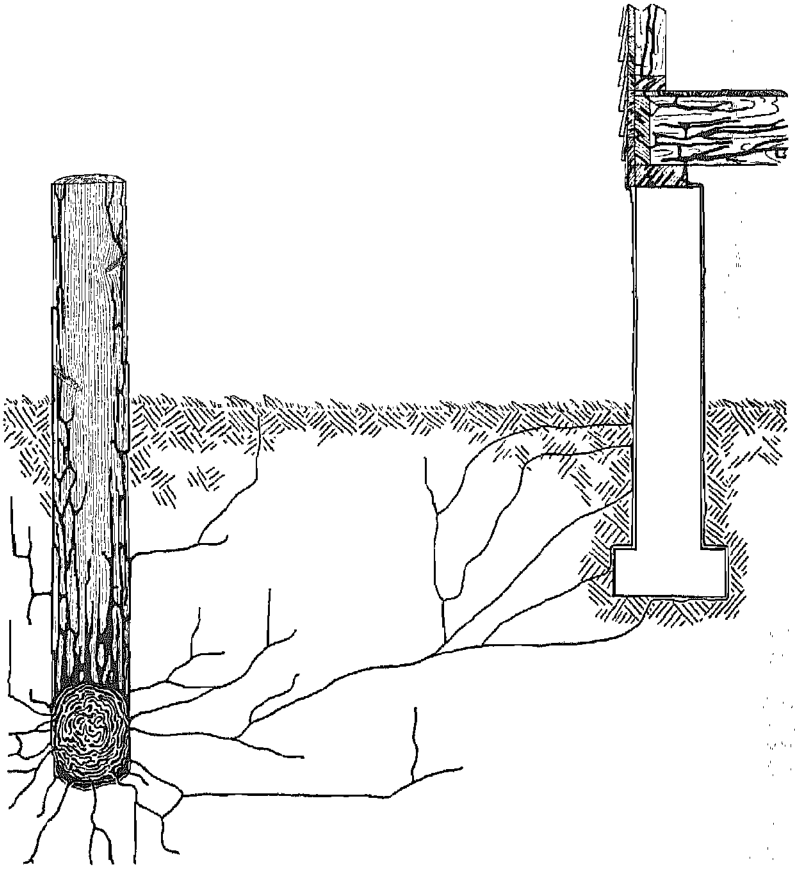


Fig. 41. Sketch showing typical location of nest and workings of *Coptotermes formosanus*, the oriental termite. The nest is in the bottom of the post. Galleries in the post connect through tunnels in the earth with runways on the outer and inner faces of the concrete foundation wall leading to the sheathing and plate, through which the termites are attacking also the studding, flooring, and floor joists.

age to houses in parts of Arizona, particularly in Phoenix, as also in extreme southeastern California and the eastern coast of Lower California.

The genus is poorly known and badly in need of revision. Besides *Heterotermes aureus,* which ranges as far south as Mazatlan, four other Mexican species have been described (Light, 1933). Two of these are known from alates and two from soldiers, and hence they may represent but two species.

LIST OF AMERICAN SPECIES OF *HETEROTERMES*

1. *Heterotermes aureus* Snyder, southeastern California, Arizona, west coast of Mexico, eastern coast of Lower California
2. *H. cardini* Snyder, the Bahamas
3. *H. convexinotatus* Snyder, Panama
4. *H. crinitus* Emerson, British Guiana
5. *H. insularis* Wasmann, Cocos Island
6. *H. intermedius* Light, west coast of Mexico
7. *H. jaliscensis* Light, Guadalajara, Mexico
8. *H. longiceps* Snyder, Brazil
9. *H. maculatus* Light, Guadalajara, Mexico
10. *H. orthognathus* Light, west coast of Mexico
11. *H. tenuis* Hagen, the West Indies, Central and South America

The species of the genus *Reticulitermes* make up the most familiar group of subterranean termites. They are confined almost entirely to the warmer areas of the north temperate zone, extending in places into the tropics where mountain chains, or the proximity of the ocean, tend to temper the climate. The belt of distribution (fig. 39) extends across the continents of the northern hemisphere, broken here and there by deserts and high mountain ranges.

The group includes the most widespread and destructive termite species in the United States, one or more of which are found in almost every state (see lists of termites by states, chap. 11, and map, fig. 42). *Reticulitermes hesperus* ranges for a short distance into British Columbia and several species range into Mexico, particularly *R. humilis,* which is found as far south as Guadalajara. Several species of restricted range are found in our southern border states. The greater portion of the United States, however, is divided between three important species. One of these, *R. flavipes*, occupies the heavily wooded and humid eastern area, ranging from the Atlantic to the Mississippi. Here another form, *R. tibialis,* is encountered, which ranges through the semi-arid prairies, steppes, and deserts of the great Central or Rocky Mountain area, and spills over to a considerable extent into the dry San Joaquin Valley of central California. A third form, *R. hesperus,* occupies the open woodlands and chaparral of the Pacific Coast area. It is with the last two species that this report is primarily concerned. It should be borne in mind, however, that these species are all so closely related that economic findings in relation to one are in the main applicable to the others.

The species of the genus *Reticulitermes* are badly in need of careful study and revision. The available descriptions and diagnoses of most of the species are inadequate or incorrect. It seems probable that careful collecting and comparative studies will show the presence of new species in some areas

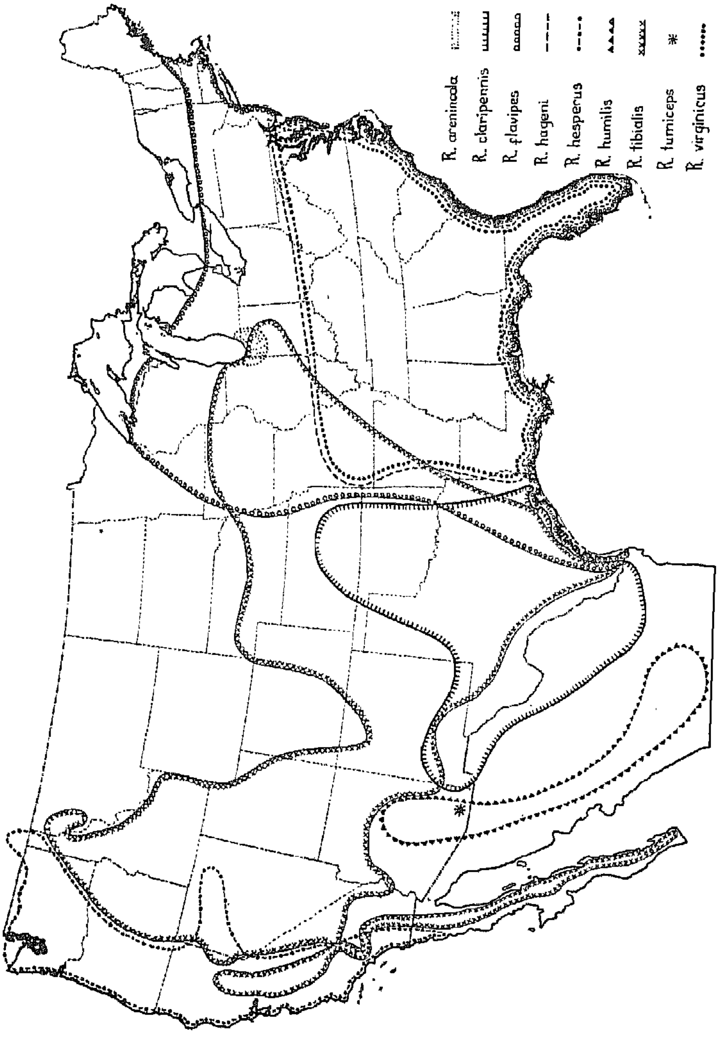


Fig. 42. Map showing the distribution of the various species of the genus *Reticulitermes* found in the United States and Mexico.

and perhaps show some of the previously named species to be invalid. A general key is not feasible in the present state of our knowledge. However, by means of the maps and available descriptions (Banks and Snyder, 1920; Goellner, 1931) it should be possible to determine any valid species with a fair degree of accuracy.

LIST OF AMERICAN SPECIES OF *RETICULITERMES*

(For distribution see lists of American termites, chapter 11, and maps of distribution, figures 42, 44, 58, 61.)

1. *Reticulitermes arenincola* Goellner
2. *R. claripennis* Banks
3. *R. flavipes* Kollar
4. *R. hageni* Banks
5. *R. hesperus* Banks
6. *R. humilis* Banks
7. *R. lucifugus* Rossi
8. *R. tibialis* Banks
9. *R. tumiceps* Banks
10. *R. virginicus* Banks

CHAPTER 14

THE BIOLOGY AND ECONOMIC SIGNIFICANCE OF THE WESTERN SUBTERRANEAN TERMITE, *RETICULITERMES HESPERUS*

BY

A. L. PICKENS

Under field conditions the amateur quickly learns to recognize the western subterranean termite in mass rather than as individuals, for only rarely do we come across an individual alone. On opening a piece of infested material we are struck by the crowded appearance and pale color of the inhabitants, conspicuously resembling a sprinkling of animated rice grains (fig. 43*a*), but on looking closer we are likely to see in the group several different sizes and forms of insects (fig. 43*a*). A few wingless individuals with elongated heads and lengthened pincer-like jaws make up the force of soldiers (fig. 43*d*). A larger group, with heavier, whiter bodies, and the rudiments of wings, constitute the older nymphs of the reproductives (frontispiece). If the colony be opened in the autumn or spring these may already have attained the darkly pigmented, winged adult stage (fig. 43*b*). Most of the group, however, are wingless, have rounded, flat heads of a pale color, and belong to the worker caste (fig. 43*c*), which does the greater part of the burrowing and excavating. On account of their gregarious habits and comparable size they have often been incorrectly termed "white ants." In the southern states and in the West Indies the agricultural class, familiar with the external parasites of hogs, fowls, and other domestic animals, have seen a similarity in the shape and color of the subterranean termites to these ectoparasites and have designated them "wood-lice." To the uninformed observer the likeness between termites and the lice often found on stock is not far-fetched. Those without the time or inclination to make strictly scientific measurements should make a careful search in opened galleries for insects of the general massing and size shown in figure 43*a*, after which more careful comparison as to shape and arrangement of legs may be made with our enlarged figures (frontispiece). The color, size, the characteristic social massing, and the steady, plodding, and unique method of movement are in marked contrast to the rapid movements of many insect lovers of darkness which on exposure rush away in sudden bursts of speed which are retarded and resumed at frequent intervals. Once familiar with these habits one readily distinguishes termites from all other insects that frequent the cavities of wood.

Distribution.—The western subterranean termite, *Reticulitermes hesperus*, occurs sparingly as far north as British Columbia, as far east as Idaho and

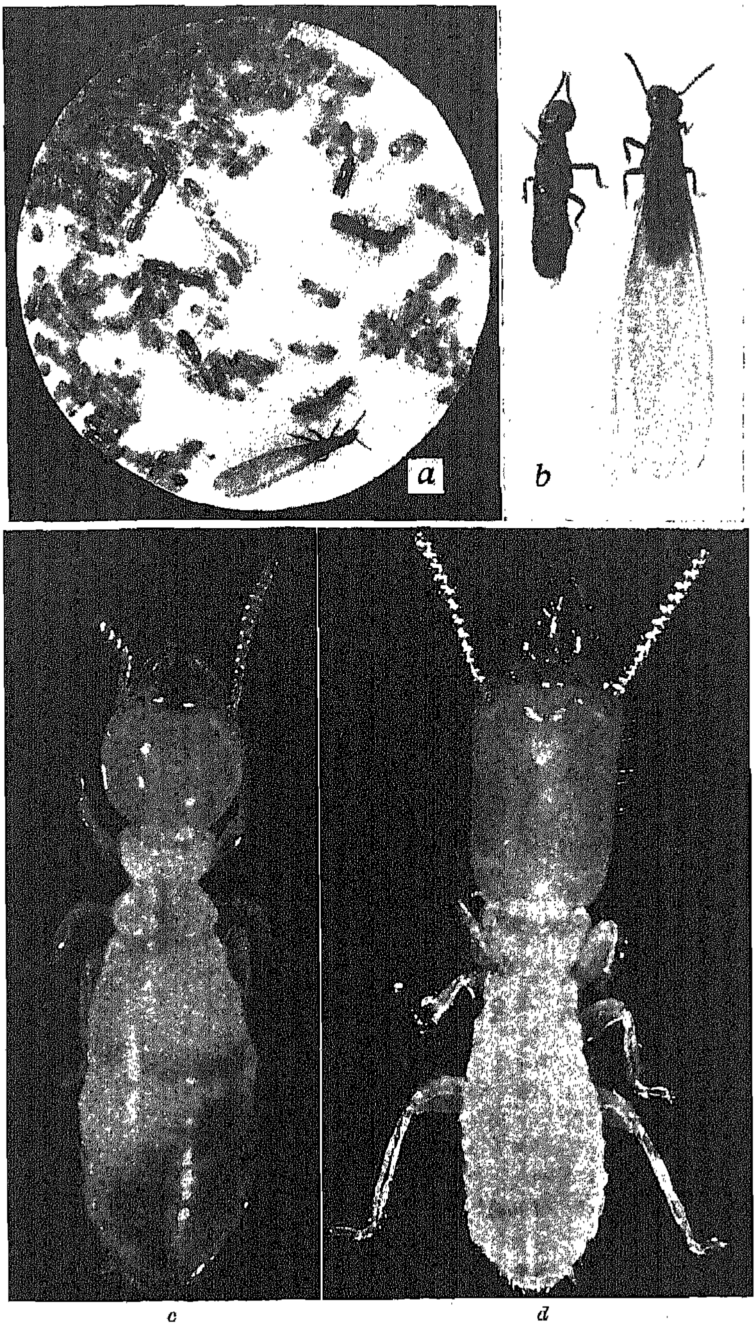


Fig. 43. Photographs of the western subterranean termite, *Reticulitermes hesperus*. *c* and *d* from *Calif. Agr. Exp. Circ. 318, fig. 22*. *a*. Group of individuals from a colony, showing the different castes and various growth stages. ×2. *b*. Winged reproductive and one which has lost its wings. ×5. *c*. Worker. ×20. *d*. Soldier. ×20.

northeastern Nevada, and southward along the Cascades and the western slopes of the Sierras (figs. 42, 44) into northern Lower California. It is not rare among the sage brush of the arid regions of northern California, but it is found only along the edge of the desert area in southeastern California, and after careful search, along the eastern slopes of the Sierras south of Lake Tahoe. In the hotter portions of the San Joaquin Valley of California where level, arid sands are found, it is almost or entirely replaced by the barren-lands species of the prairies and Great Basin, *R. tibialis*.

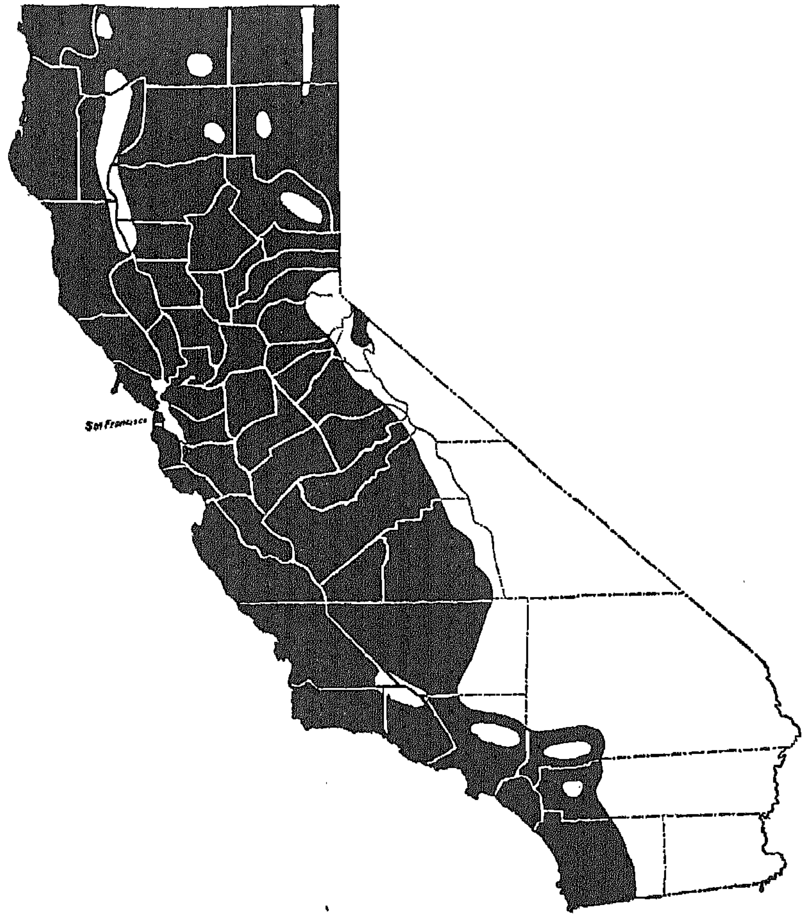


Fig. 44. Map showing in black the distribution in California of the western subterranean termite, *Reticulitermes hesperus*.

Size, location, and make-up of colonies.—The numbers of individuals in colonies of the western subterranean termite range from three or four to several hundred thousand, depending upon their age and location. A section of a beam less than half a cubic foot in volume can house as many as four thousand individuals, while colonies formed by newly mated pairs may run for a year with no more than five to ten individuals.

The colonies are nearly always located in proximity to damp earth, being situated either within the earth or in wood connected with it by closed tunnels. In pieces of infested material the insects may maintain themselves for weeks after the wood has been lifted from the earth, by sealing all openings. Each colony has at least one queen, but there are often several, depending on the size of the colony. The queen is usually attended by a male, but seems able to lay fertile eggs for a considerable period after her consort's death. She lives in a large chamber with the male, attended by a guard of soldiers, and from time to time shifts her quarters to some neighboring cavity of similar size. The tunnels constructed by the workers in wood and earth radiate in irregular reticulations with no particular plan, though each colony has an arrangement, or rather disarrangement, of its own, and the burrows have a general characteristic pattern unlike that of other termites.

THE LIFE CYCLE

Swarming and pairing.—As was previously noted (p. 147), a colony of these insects will usually be found to contain thousands of winged individuals, changed after the last molt from the usual whitish color of the nymph into a sharply contrasting black (fig. 43*b*). These remain in the subterranean quarters in company with the pale workers for weeks, and even months, awaiting the first heavy autumnal rain. When that has fallen and the soil is thoroughly soaked, the insects crowd to openings provided by the busy workers, and on the first clear day that follows the rain, if the temperature is not too cool, they emerge by the thousands. Careful comparison of data gathered in various parts of the state shows that the zone of first emergence coincides with the zone of first rains from the sea coast inward. In the San Joaquin Valley, California, both ***Reticulitermes hesperus*** and ***R. tibialis*** may emerge on the same day. As the rains continue farther inward to the desert, the barren-lands termites may make up the bulk of those emerging on the eastern side of the Sierras. In southern coastal California, and inland as far north as the Sacramento Valley, another swarming occurs in the spring, and a few colonies along the central and northern coast regions of California send forth alates at the same time.

The first rains bring out those nearer the surface, but for the colonies far back under houses or wide pavements, a second or even a third or fourth rain may be necessary to penetrate to their quarters, and those making up the last autumnal swarms may loiter in their galleries until December, or even January. If the fall is very dry the majority may stay thus penned up until late in the season. In California, during the record dry fall of 1929, the great majority of the alates remained in the ground until a hard rain about the tenth of December. Having been detained for so long, when the showers slacked, millions of the insects crawled out without waiting for brighter weather. Needing the impulse of sunlight to induce flying, they crawled about on the ground until thick clouds and darkness brought a chill which induced many again to seek their underground burrows. In some places the insects were packed by the hundreds against the entrances, their wings away from the openings, the whole giving the appearance of a rosette, the petals of which were formed by termite wings. If the temperature is 64°F., or higher, the insects readily remain outside and may fly aloft even with a slightly clouded sky above them.

As the rain soaks downward into the soil above or near the colony, the whole group is attracted upward to the new supply of moisture, and will even work toward it through a dry layer. The workers do most of the excavating. They are attended by a small guard of soldiers. If any foreign insect attempts to gain entrance into the burrows through the newly opened exits, the soldiers aid in dispatching them by means of their long, sharp mandibles. Behind these groups of guards the winged alates orient themselves with their heads pointing toward the newly opened doorways. As the upper layers of the soil are warmed by the sun they are drawn toward the surface and, crowding and squeezing, swarm into the outer air. If the sky is flecked with clouds, the alates collect about the entrance of the burrow, but when the sunlight strikes the opening the whole group springs into the air and flutters toward the sun.

The flight is weak and the direction is largely determined by the prevailing breeze; most of the insects soon sink to earth in the immediate vicinity, though a few may flutter upward for sixty feet and be borne along for as much as two hundred yards. Many do not fly aloft at all, but drop their wings while running about on the ground. At times these wingless ones apparently feel the impulse to fly as the sun warms their bodies, for they leap vainly into the air. Those that have been aloft settle to the earth and, raising the rear of the abdomen, push it against the wings, which break off at natural sutures near the thorax, leaving four little stumps (fig. 1*b*, *h*). The females now take up a passive position with the abdomen raised high in the air, increasing the area of visibility and probably emitting an odor which is attractive to the males. The latter rush about the surface hurriedly, one by one coming in contact with a female. When a pair thus come together the female depresses the abdomen and the male follows as she leads, the two proceeding in tandem, sometimes joined by a third and even a fourth insect, the whole moving along like a train of cars. At times, in turning, the leader curves so far to the right or left that she finds herself behind the last one of the train and the group revolves for some time in a circle. Again, the male may become separated from the female leading him, in which case she stops, re-elevates the abdomen, and waits until he or another male joins her before proceeding again.

Establishing the primary colony.—Curiously enough, these insects, which a few minutes before were so eager for light, are now just as strongly repelled by it, and the female, followed by the male, seeks shelter. The pair may dig for some distance to find wood, or may crawl under, or into a crevice of, some piece of wood on the ground nearby. At times more than one pair may thus enter the same cavity. Until a suitable cavity is reached, the male follows passively in the rear, but once such a site is found the tandem is broken, and both male and female set to work industriously excavating and cleaning up the new home. Wood fragments and fecal plaster, with bits of debris, are stuffed into the cracks, the walls and floor of the cavity are smoothed and cleaned, and an irregular cell is constructed, usually less than an inch in length, and less than an eighth of an inch in width. As the work progresses, and the cell assumes form, the pair stop from time to time to feed or to groom or clean each other with their complicated mouth parts. Copulation, which sometimes occurs the next day after digging in, is preceded by a period of grooming, the male sliding along the side of the female's body until both bodies are in line and the tips of the abdomens in contact. Direct contact continues for as much as one to two minutes. Copulation has been observed to be repeated at intervals for some months, and probably actually occurs at intervals throughout the life of the royal pair.

Egg laying.—The rate of mortality among primary reproductives is high. Thousands may perish in the dust and dry soil, or may drown in succeeding showers after the nuptial flight. Others fall prey to birds, or to ants and other insectivorous foes. Of the few that succeed in establishing themselves many probably perish because of unfavorable conditions, such as excessive dampness or dryness. Still others wander about, and spend so much energy in excavating huge and useless burrows that they are unable to produce the full quota of eggs. However, with those that are successful, an average of less than ten eggs is produced as a first clutch. The number may be as low as four or six, or as high as fifteen, or in rare cases twenty. The eggs are laid at fairly regular intervals. A period of from one to three days elapses between the deposition of two successive eggs, except for the last two or three, which are laid at increasingly long intervals, as much as a week or ten days.

Care of eggs and young.—Some care is used in attending the eggs. They are usually stacked carefully together on the floor of the cavity and from time to time are taken in the mouths of the reproductives and thoroughly cleaned. Eggs which are deprived of this care lose brilliancy, grow mold, and fail to hatch. The period required for hatching runs from thirty to ninety-nine days, or even more, an average being fifty to fifty-six days, the first eggs hatching in the shortest length of time and the later ones requiring increasingly longer periods. As the incubation proceeds, the eggs slowly increase in size until just before hatching, at which time the cubic mass of the egg is three times what it was at laying. The head and legs of the insect are distinctly visible through the transparent covering, and the development of the segments of the abdomen may be roughly traced from day to day. As the size increases, the shell splits at a point just back of the head and is drawn down tightly over the forehead and mouth of the young insect. The body fits tightly in the shell, which now ruptures along the mid-dorsal line as the creature struggles to free itself. By this time the attention of older members of the colony will have been drawn to the struggling young termite. One of these older termites now takes the young individual in its mouth, while one or two others assist in lifting or pulling it from the shell. It is then carefully groomed, each leg being passed through the mouth of an older individual and thus cleaned of the albuminous material which sticks to the legs. The young nymph soon begins to walk, making its way about on slow, uncertain legs (fig. 1*c*), and standing in a half-crouching position, which brings its mouth on a proper level to solicit or even to seize food from the anus or mouth of the parents or of the workers. This food is a substance which seems to be secreted in the intestine and obtained by anal feeding by various members of the colony. At times the very young, in the crouching position just mentioned, are seen to obtain food from the anus. In less than a week they are also feeding on a brown fecal plaster, of which there is usually an abundance about the nest.

The developmental stages.—In about fourteen to eighteen days after hatching the insect has grown so large that it is necessary to cast its skin in its first molt. It then passes into the *second stage,* or *instar,* during which it is found to contain the intestinal Protozoa common to the older members of the colony. A similar period is spent in the second growth stage, or instar, and after a little more than a month the second molt occurs and the *third instar* is entered. This instar lasts for approximately a month, and the *fourth instar* for about two months. In young colonies started by a swarming pair the fourth instar, or a small *fifth,* may be the dominant instar in the colony for as much as two years. *Sixth instars* result in the development of large, well matured workers and of reproductive nymphs, but only in colonies sufficiently large to supply abundant food and a large amount of fraternal feeding, which seems necessary to such full development. Even then such large forms are hardly to be expected in less than eight to twelve months. In very old colonies, a number of years old in fact, some of the larger nymphs appear to pass into a *seventh instar* as still larger workers. This is also the instar at which the perfect reproductive stage is attained in the reproductive caste. Reproductives, however, may attain the seventh instar in from two to four months after the sixth instar.

Growth in the primary colony is very slow. Most of the first individuals to become mature are dwarf workers. A few are dwarf soldiers, which change into the preliminary soldier stage at the fourth instar, run through it in from ten to fourteen days and emerge as adult, but diminutive soldiers in the fifth instar. As the colony grows, and more mutual feeding is possible, the soldiers take a longer period to develop and are correspondingly larger. In very old large colonies in favorable localities some of the soldiers appear to delay full development until the seventh instar. The development of reproductives require several years of growth and an abundance of inhabitants, depending apparently on the abundance of material supplied for interfeeding. Swarms, even under highly favorable conditions, cannot be expected before the third or fourth year, at the earliest. Those observers who expect a rapid increase in the population of these colonies sufficient to produce thousands of flying alates the third or fourth year after the colony has started, are doomed to disappointment. A definite, unequivocal statement of such an increase is rare or lacking in the literature, and the strength of the termite colony seems to lie, not so much in a rapid production of short-lived individuals, a condition we find in the beehive, but in the long life of those produced. Workers that do not fall victim to cannibalism may reasonably be expected to live from three to five years, and queens probably live much longer.

THE RÔLE OF THE SUPPLEMENTARY REPRODUCTIVE

Heretofore, with the exception of the Italian observers (Grassi and Sandias, 1893), students of *Reticulitermes* have supposed that the huge colonies found in nature come from the alates which fly abroad at certain seasons, cast their wings, pair and enter new quarters in or near the ground. It was with this point of view that experiments were begun in the laboratory and test yard to determine the rate of growth of colonies. About six hundred potential colonies were set up in a variety of situations, many of them under the most favorable conditions possible. Some were carefully planted in a cool, shady grove on the campus of the University of California; but the situation was too cool and such eggs as were produced did not hatch. Others were placed in a cage in a sunnier and more favorable situation. Native workers already in the same territory explored the surface of the cage beneath the ground, found openings just large enough to allow them to enter, and destroyed all but four reproductives and a few workers out of a number of healthy colonies. This indicates the possible fate of most of those reproductives that attempt to start new colonies in soil already preëmpted. Forty colonies in a box of soil, with no possibility of such invasion, and a large number in observation glass vessels, have in general thrived, but so slowly as to make it clear that primary reproductives cannot possibly account for the large swarms that have been found in houses built only eighteen months to two years. Feeling that artificial heat found in dwellings might be an accelerating influence, a large cage heated by a steam pipe was equipped with wood and other necessary material, and a number of potential colonies, some of them already under way, were introduced. Within a few months fungus, growing luxuriantly because of the constant warmth, wiped out all of the insects so placed.

Nor is the possibility of adoption, which has been suggested for other species, tenable. All efforts to have a group of workers adopt a queen have failed. Primaries introduced into a strange colony are immediately set upon by an aroused mob and chewed to a pulp, which is mixed with macerated wood and buried on the floor of the gallery. Attempts to segregate the primaries with workers from their own colony are not successful, the reproductives eventually disappearing. With secondary reproductives no better results are found. One group of wingless workers segregated for four months killed within twenty-four hours a secondary queen thus presented.

One more possibility that presented itself seemed worthy of trial. In naturally established primary colonies brought from the open field from time to time, as well as in those set up in the laboratory, it was noted that aggregate colonies were formed by several pairs entering one chamber and combining the resultant offspring into one colony. Experiment, however, showed this to have limitations, for where the number of reproductives was made too large the offspring suffered from neglect and probably from cannibalism. The most rapidly growing colonies are those in which the union occurs, not at the swarming time, but after the several colonies have got well under way, and each has a number of young and of workers. If the cells are sufficiently close together, the reproductives and workers in their excavations cut through the dividing walls, and after some fighting among themselves merge into a single colony in which one by one the reproductives are killed until a single pair is left to receive the care of the much enlarged worker force. Under these conditions development is much more rapid, but even so it seems to be impossible to bring the queen to a condition of sufficient physogastry to enable her to continue laying regularly through the first hibernal and aestival periods. It should be stated that primaries usually take a rest during the summer and winter mid-periods of the first year or two, during which periods they do not lay at all, or else lay only at very long intervals. The most rapidly developing of all primary colonies observed, living under the most favorable conditions, had only about 250 inhabitants at the end of twenty months. In the field, colonies increase in population more slowly even than this.

An explanation for the early infestation of houses was sought in the presence of supplementary queens. It was found that groups of workers and nymphs, when separated from the mother colony, were existing in from six to eight weeks as a new colony, with supplementary queens that had developed from some of the short-winged nymphs found in every large colony, in addition to the nymphs that develop into flying alates. Considering the slow development of the winged form and the even slower onset of regular egg laying, the development of these supplementary queens is accomplished in a marvelously short time, our earliest record for the first egg seen after separation of the colony from the mother group being forty-one days. What is more, as high as three queens may develop in the same cavity and live peaceably together, with the eggs from all three deposited in a single pile by the workers. A supplementary queen attains approximately the physogastric size in a few weeks, and at the height of egg-laying will deposit more eggs in a day than the primary queen lays in the first two years of colonial development. Some of the largest supplementary queens can lay sixty to eighty eggs a day. A small group of one hundred termites segregated from the mother group can thus develop a new queen and increase the size of the colony to six hundred individuals in the first year. Larger groups of five hundred to a thousand can care for a proportionately larger number of queens. The significance of these figures increases when we remember that half a cubic foot of wood can comfortably house four thousand of these termites with all their galleries.

Queens are not produced as among bees by a special process on the part of the workers. In fact, they grow up among nymphs segregated from workers. Such queens, however, do not thrive, the sister nymphs being too sluggish to perform the proper functions in the new colony. The supplementary reproductive which first develops reproductive characters may possibly secrete a substance that inhibits sexual maturity in her sisters. If a number are at about the same stage of development they may attain the reproductive stage simultaneously. In very small groups with only a few workers these supplementary reproductives develop but do not thrive as well as in larger groups. In groups of seeming workers from which all winged nymphs were continuously excluded, absolutely wingless supplementary reproductives appeared after ten months.

Thus we may roughly liken the growth of the *Reticulitermes* population in a favorable area to the growth of a well established forest of trees, which by ramification of roots and overshadowing of branches preëmpt all the soil. Seeds produced by such trees, dropping directly below, must perish. By decaying and enriching the soil they may serve as food for some other organism, or even for their own species, but only those seeds that reach unpreëmpted ground can become trees, and that only over long periods. Thus it is with *Reticulitermes*. The great majority of the alates must perish in preëmpted territory, or serve as food for other organisms, such as virulent fungi, birds or lizards, and many may even serve as food for their own cannibalistic relatives. Only a few, finding uncontested territory, are able to establish new colonies.

Colony Activities.—The larger colonies have much in common with the smaller ones, so far as social habits and castes go. The queen, as the number of workers and feeders increases, gains the ability to lay more eggs, and occupies some large cavity at a distance from the surface, where she is attended by a retinue of soldiers. Workers are constantly repairing to this cavity, feeding the queen and grooming her, thereby obtaining exudations from her body, as they do from other workers. They bear the eggs away as she lays them and pile them in the cavities which afford the most favorable temperature, and when they hatch bestow more or less care on the young, which, curiously enough, in the large colonies are smaller in the second and third instar than in small primary colonies. At the fourth instar, however, workers of both large and small colonies are again similar in size. This probably has some connection with parent feeding, which, in a large group, cannot by any means be applied to all young individuals.

The mandibles (fig. 6) and other mouth parts are the universal tool of the termite workers and with these they perform the gentlest offices of the colony, going carefully over the body of the queen and fellow-workers without injuring them in the process of grooming, gently lifting the young and the eggs and carrying them from place to place; and yet when necessary carving a way through sound timbers, using them as a weapon of offense in battles with members of foreign colonies, carving off limbs, or severing the heads of other termites. With the mandibles and other mouth parts particles are carried, as among ants, for building purposes. While a majority of the passageways are tunneled through earth or wood, others are carefully constructed arched tunnels leading over outside surfaces or through subterranean cavities into which the explorations of the termites sometimes lead, but which are too large to police with safety. These archways are built up, a particle at a time, with grains of sand or earth, or minute bits of wood (fig. 45) carried by the mouth parts from elsewhere in the colony, coated with a gluey substance in the mouth and gullet, and ejected carefully on the edge of the arch, somewhat as a mason lays on a new stone. The adhesive quality of this buccal glue is surprising. Around furnaces in heated basements termite runways sometimes take the form of tubes built into roughly vertical towers (figs. 46, 47) that rise to a height of as much as two feet. Although in some cases made of friable soil particles so loosely cohering that the light penetrates the wall as through a coarse filagree, and so yielding as to sway slightly in the wind, they are remarkably resistant to destruction. Again, these tubes drop down from beams that have been heavily infested, as if the insects sought a new contact with the earth. In this case lighter wood fragments may take the place of the heavier sand grains to a large extent, and such tubes can hold their own weight and extend downward unsupported, save at the upper end, for as much as thirty-five to forty inches (fig. 49). The vertical towers appear to be constructed only at swarming times for the exit of the winged reproductives. In the open they rarely rise higher than four to eight inches, but in dark, well warmed basements they may rise to the surprising height of two feet. The insects building in the dark seem to respond instinctively to the warmer and ever warmer

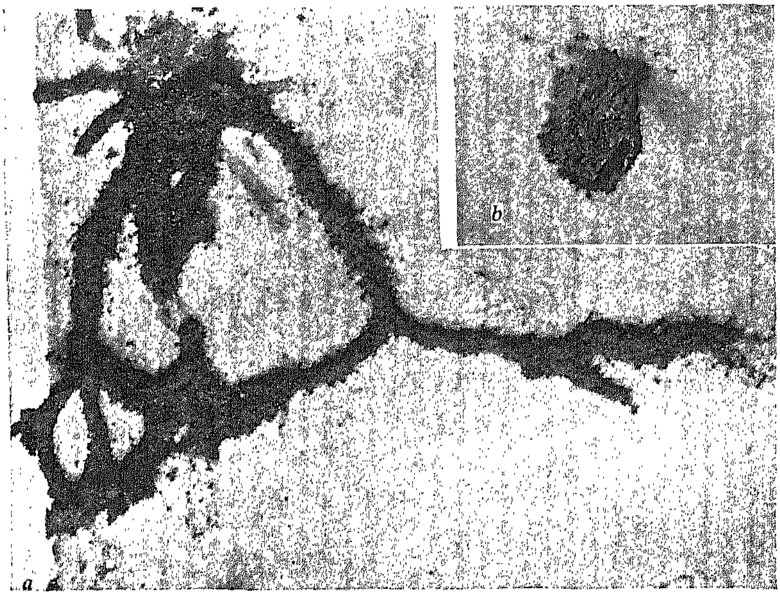


Fig. 45. Tubes and covered ways, extending the conditions of the colony home in the earth to their workings in wood, are characteristic features of the activities of all subterranean termites. These tubes are composed of tiny particles of earth or partly digested wood. The western subterranean termite, *Reticulitermes hesperus*, builds these very extensively in southern California, but rarely does so in the central and northern portions of its range. That it can do so is indicated by the photograph *a*, which shows in natural size the runways built in a single night in the Termite Investigations Committee's laboratory in Berkeley by a group of termites removed from ground connections. The initial stage in the construction of a hanging tube is shown in *b*. × 2. From *Calif. Agr. Exp. Stn. Circ. 318, fig. 28.*

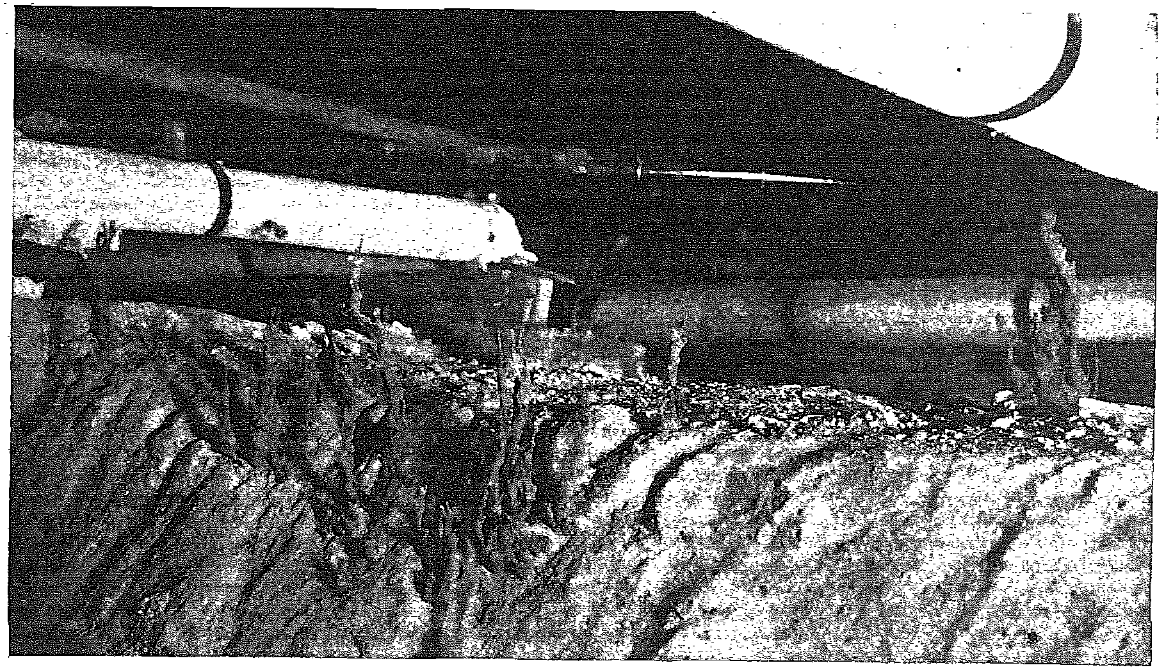


Fig. 46. Termites shun the light and live entirely shut off from the outside world. In their search for wood to eat, the subterranean termites build their dwellings in advance in the form of tiny tubes or covered runways made of thousands of particles of earth or wood cemented together by excretions of the termite. Each tiny particle is brought separately and put in place by a worker termite. Only the subterranean termites build these structures; the wood-dwelling termites are confined to the cavities which they excavate within the wood. Heat is favorable to such activities, and such towers are frequently found in furnace rooms or running up to furnace pipes, as in the photograph, and from there up to the floor above. From *Calif. Agr. Exp. Stn. Circ. 318, fig. 2.*

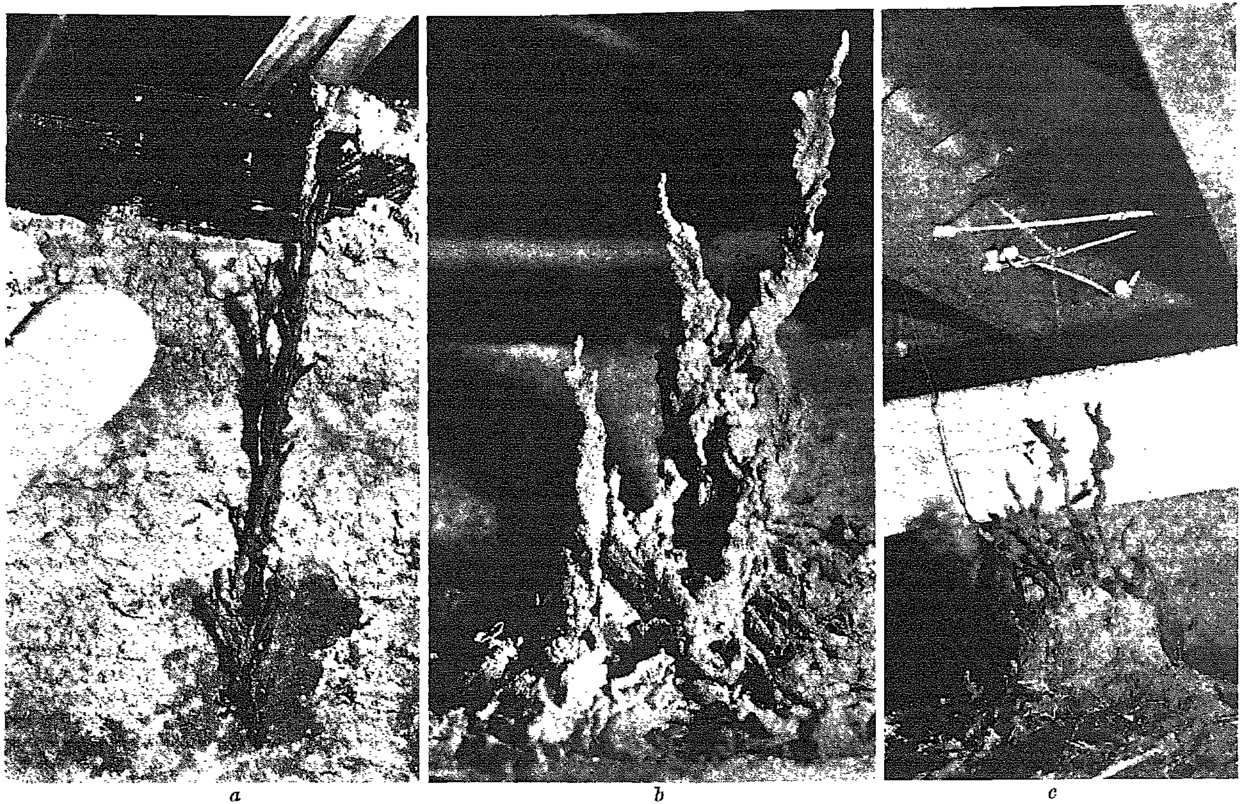


Fig. 47. Runways, tubes, and towers made by subterranean termites under houses. *a*. Branched tubes of a species of *Reticulitermes* originating from a wood spreader embedded in concrete foundation. Wood forms had been left on the outside concrete wall of the building, which was only two and a half years old. From photograph by T. E. Snyder. *b*. Towers of the western subterranean termite, *R. hesperus*. *c*. Towers and tubes of the western subterranean termite, from a stump left under a house to furnace pipes above.

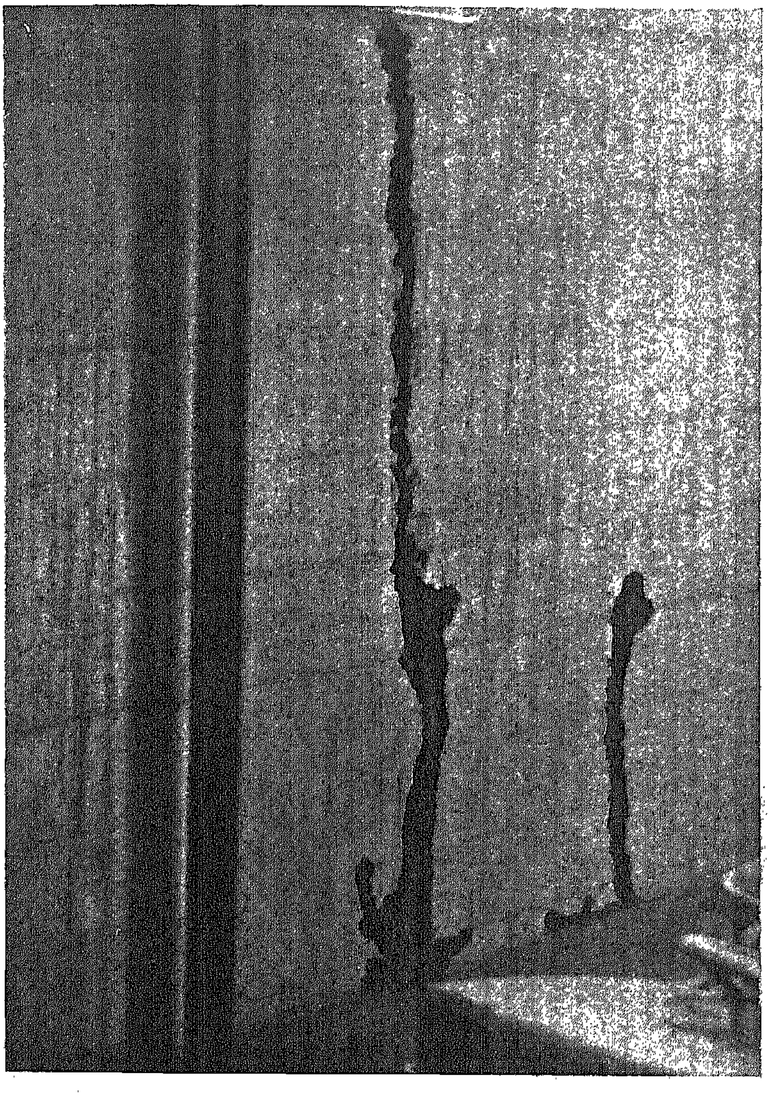
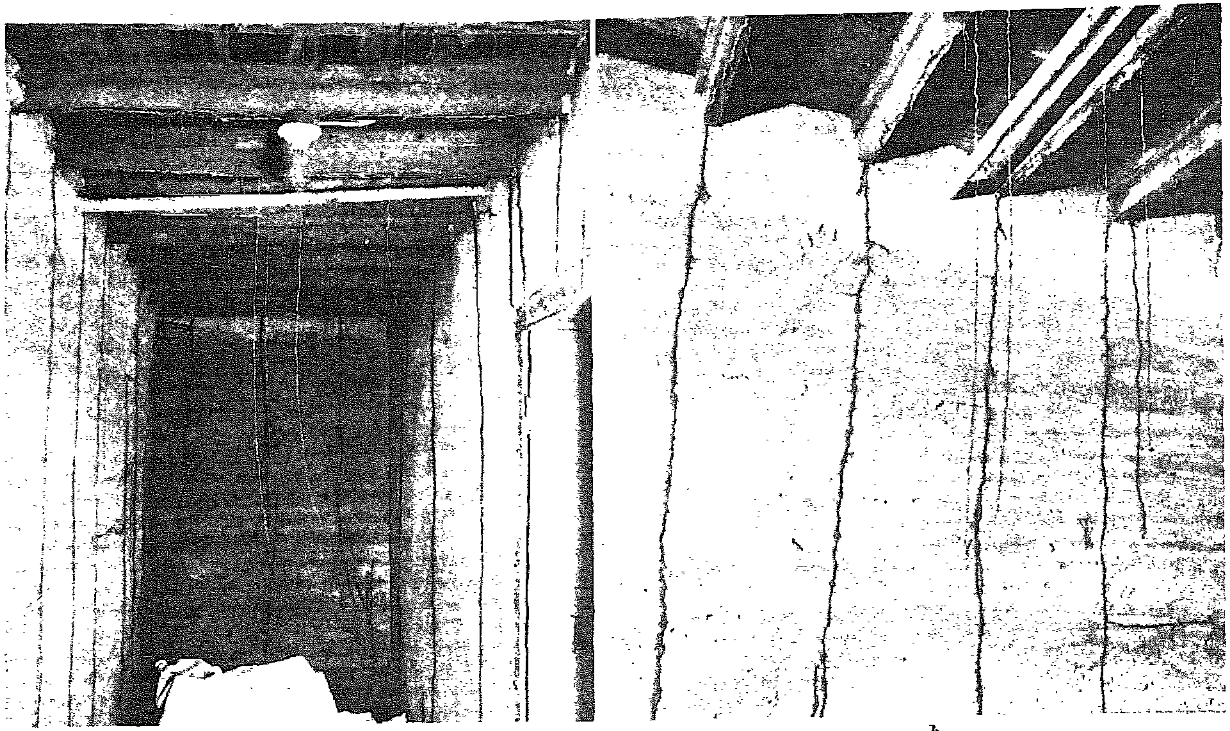


Fig. 48. Covered passageways composed of particles of earth and fragments of chewed wood, constructed by subterranean termites on vertical concrete walls for two stories in a heated warehouse, in the San Francisco Bay region. From *Calif. Agr. Exp. Stn. Circ. 318, fig. 20.*



a *b*

Fig. 49. Photographs showing suspended tubes and runways passing downward from infested joists, made by *Reticulitermes* in Florida. From photograph by T. E. Snyder. *a*. General view. *b*. Partial view of left wall.

layers of air that lie one above the other beneath the floor, just as they respond to the warmer layers of soil above their colony; but on reaching the outer air in the dark and finding no sunlight they react to the huge basement space just as they would to a large subterranean cavity in the soil, that is, they attempt to build through it and reach the sunlight above. Cases have been reported in which tunnels so built struck the woodwork above and were used as runways to connect this new food supply with the colony beneath (fig. 47*a*). Refuse heaps or dumps of their own creation play a large part in the building and social activities of the colony. For instance, not all of the wood chewed out of timbers is eaten, nor is it cast outside to give evidence of the presence of the group. Instead, it is carefully transported to the rear, and piled into some large interstice, such as a natural cavity in the wood or soil, or perhaps an over-enlarged gallery no longer needed. It is even possible that such material, mixed with fecal plaster and carefully placed about the edges of the wall (figs. 52, 53), may tend to become more suitable food under the action of microorganisms, particularly for the younger individuals.

During the course of construction a small soldier guard attends the workers. When outside archways are being constructed, ants are likely to invade the openings at the end, in which case the soldiers rush forward and attack the invaders with their sharp, pincer-like mandibles, while their tender and vulnerable abdomens are protected by the archway, from which they do not venture any great distance. In tunneling through decayed or sound wood the workers are likely to encounter large beetle larvae, which they attack and destroy, often not without a considerable loss among the attackers. If two colonies of termites come together, terrific encounters occur, in which scores and even hundreds of workers perish, for these insects are antagonistic not only to other species of insects, but to any member—soldier, worker, or reproductive—belonging to another colony.

ECONOMIC IMPORTANCE OF SUBTERRANEAN TERMITES AND THEIR RELATION TO CIVILIZATION

In nature, undisturbed by man, the subterranean termite plays a valuable rôle. Like the earthworm, it aerates and mixes the soil, carrying more fertile surface soil and nitrogenous products from its own body far into the less fertile portions of the ground. Furthermore, it is capable of attacking and reducing to a state of mold, cellulose of so solid a nature that the earthworm is not capable of handling it.

Immediately man appears on the scene he makes the environment increasingly favorable for the subterranean termite. The dense, shady forest is cleared, letting in sunlight, often to a cluster of stumps or roots which thus exposed furnish both incubating heat and food for much larger colonies than had been possible before. On the already open and sunny prairie, water is supplied in larger quantities than was previously available for the insects. Watering troughs, flower beds, and irrigated areas offer new opportunities for growth, and the termites take toll of all wood left in contact with the ground for any great period (fig. 50). Fence posts probably suffer most, and even resistant woods, if untreated, are liable to honeycombing beneath the ground level and as far above as the insects can control temperature and moisture conditions. Planks, fencing, outbuildings, and even dwellings too near the ground, board walks, and temporary stakes are susceptible. In areas near strong colonies, freshly painted, sound stakes planted in the ground are riddled within six weeks. But since much of this damage is to structures of secondary importance, termite damage is often unnoted and attributed to natural decay.

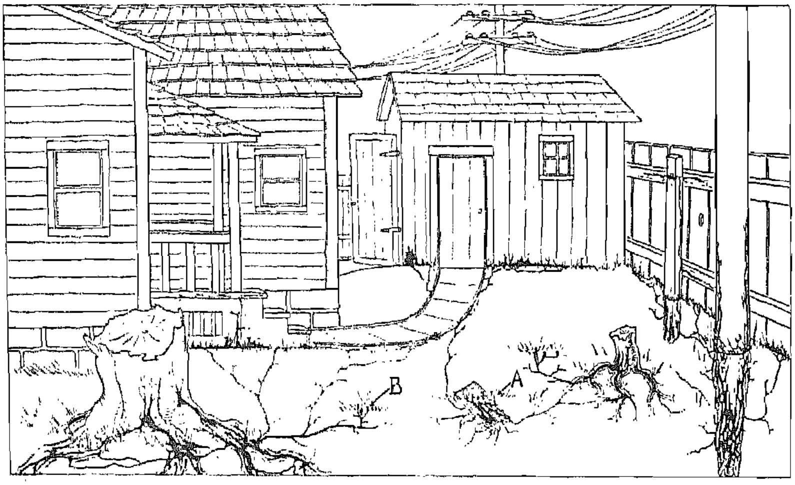


Fig. 50. This sketch combines the sorts of conditions found to prevail in many localities where wood has been improperly used. Unprotected wood in or on the ground makes possible both settlement and rapid increase of the subterranean termites. Workings in stumps, poles, posts, sidewalks, and wood of buildings are shown in black, as are the galleries within the earth. *A* marks the supposed original point of entry of one of the colonizing pairs, and *B* the points of emergence of swarming alates at the proper season.

As urbanization and industrialization of a community continue, termite damage increases. Poles are attacked, first under the ground level (fig. 52), and, as the colony grows, upward along the pole to heights of twelve and fifteen feet, depending on moisture and temperature. The earth and dampness thus carried up aid fungous decay, and the two together detract greatly from the service-life of the pole. Cross-ties on spur tracks are often attacked, but, fortunately, ties on main lines in the United States seldom are.

The number of termite colonies in a given area varies widely because of differences in supplies of food and moisture, temperature, etc. A picture of the distribution of termite colonies in a definite area as ascertained by routine inspection may be of interest. Crockett is a small town on the Carquinez Straits at the upper end of San Francisco Bay. The California and Hawaiian Sugar Refinery is located there. This corporation was a cooperating member of the Termite Investigations Committee, and Crockett was one of the earliest sites investigated for termite damage. Figure 7 gives some idea of the prevalence of subterranean termites in Crockett as evidenced by the location of swarming alates. Figure 51 is a diagram of the wood yard to the east of the company's large warehouse, showing the location of termites as brought out by a fairly careful examination. The fence on the east faced a squatter settlement along the shore of the Straits in which great quantities of exposed, usually moist wood made excellent breeding grounds for *Reticulitermes* and *Zootermopsis*. *Reticulitermes* was found in small pieces of wood along the base of this fence (fig. 51, (1)); in the bases of the posts of this fence (2); in the old posts and new stubbings of the fence on the southeast (3); in the wooden structures connected with a saw (4); in the wooden structures underlying a small pile driver (5) which had been in place but six months; in the wood underlying the large pile driver (6); in the props to the fence on the southeast (7); in casual wood on the ground (8) and (9) (and other pieces

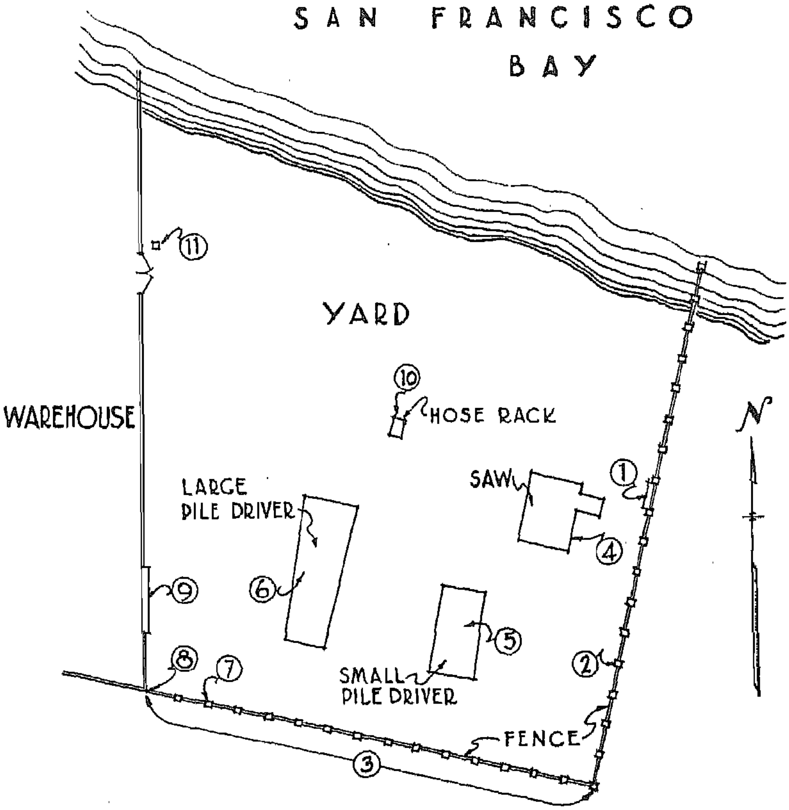


Fig. 51. Diagram to show the location of the separate groups of termites found in wooden structures in a wood lot on upper San Francisco Bay, as discussed in the text. Numbers indicate the locations of the separate infestations.

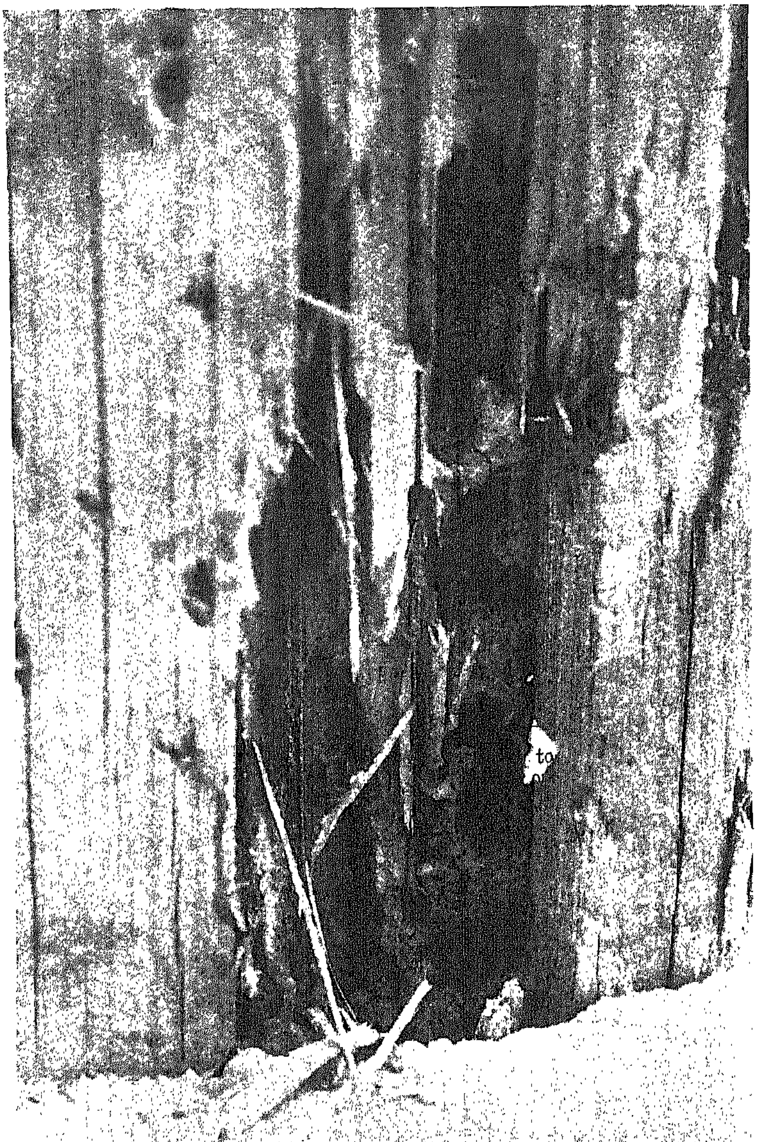


Fig. 52. Photograph of the sapwood of a pole infested with *Reticulitermes hesperus*, opened near the base, showing the characteristic deposits of earthy material and wood waste, and the oval yellow spottings on the walls of the galleries. From *Calif. Agr. Exp. Stn. Circ. 318, fig. 21.*

not numbered); and in timbers underlying the fire hydrant curbing (10), which were continually moist. In the last location there were numerous incipient colonies. *Zootermopsis* was also found with *Reticulitermes* in two of these locations (4) and (10), and alone in a piece of wood 8 inches × 8 inches (11).

The subterranean termite has attracted much attention because of its depredations on dwellings and commercial buildings. The tendency has been on the one hand to exaggerate, and on the other to minimize, the importance of such attacks. Few, if any, buildings actually collapse, but local damage to floors, walls, wooden terraces, and steps in contact with the ground is very common. Considerable damage is done to supporting beams and studs, and subsidence or partial collapse could occur where such timbers are sufficiently hollowed out by the termite colony. Strange as it seems, only one case of actual collapse has come to the attention of the Committee.

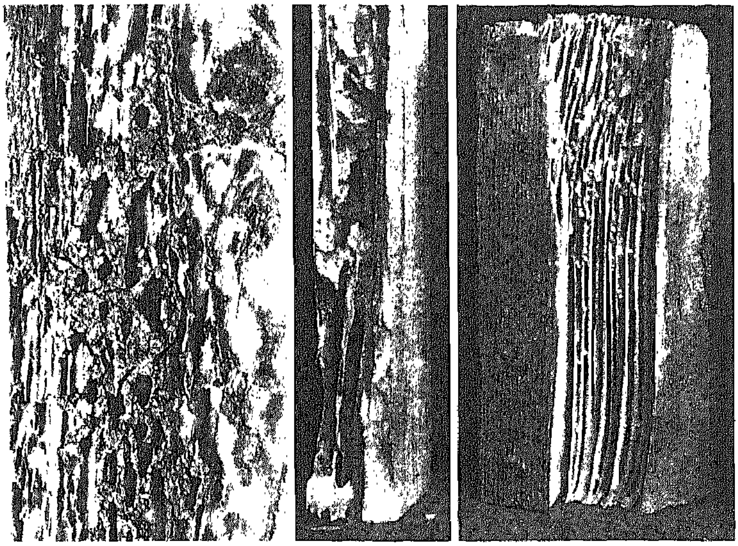


Fig. 53. Three photographs of workings of *Reticulitermes*. All show the earthy frass characteristic of the subterranean termites. The tendency to select the soft portion of the annual rings is shown in *b* in coarse grained wood, and in *c* in close grained wood. In both cases the work was wholly internal, without external evidences of its existence except at the ends of the members. In *a*, however, the attack was from the surface, since the member was concealed under a protecting layer. Pieces *a* and *c* were sound wood, without visible evidence of fungus attack.

One of the serious aspects of the problem lies in subterranean storage basements and concrete bank vaults. Into the first, termites at times make their way from the surrounding soil to build over the walls and attack stored boxing and furniture, while a hole the size of a match stem in a concrete wall will serve as a passageway through which hundreds of the insects crawl to destroy such furniture or documents as lie in their way (fig. 54).

Examinations made on scores of buildings attacked by termites point definitely to the conclusion that buildings can be so constructed as to be almost if not entirely free from attack. Buildings within the termites' range, and for some distance beyond places where artificial temperatures may be favorable to their growth, should be built with a knowledge of the biology of these widespread destroyers of wood. Biological and structural control is entirely possible where a building is erected with a full knowledge of the habits of the insects. If a building has been erected according to a faulty plan (fig. 55), or if poles and fence posts are being placed, resort may be had to chemical treatment or other preventive measures for adequate protection.

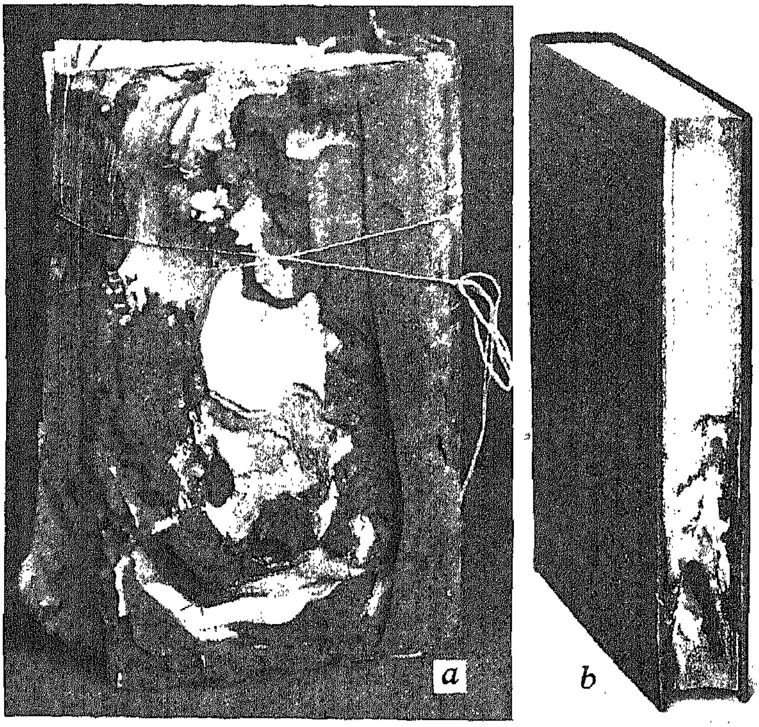


Fig. 54. Books from the shelves of a metropolitan bookstore destroyed by *Reticulitermes*. *a.* A Latin grammar. *b.* A copy of *The Voyages of Sir Francis Drake*. The lack of intellectual progress in the tropics has been correlated by some writers with the rapid destruction by termites of printed or written records. From *Calif. Agr. Exp. Stn. Circ. 318, fig. 29.*

An interesting opportunity was offered to observe the relation between various construction conditions found in old houses and the activity of subterranean termites when some fifty contiguous dwellings were torn down at Berkeley to enlarge the grounds of the University of California.

Four adjacent city blocks were cleared of buildings varying in age from ten to sixty years. The dwellings were mainly old, approaching obsolescence, and built prior to the adoption of modern building codes. Their impending removal was known for several years and therefore there was probably lessened vigilance in maintenance. Of the fifty buildings inspected forty-five were damaged. Estimates of the cost of repairing the damaged structures ranged from five dollars on a recent building to two thousand on an older

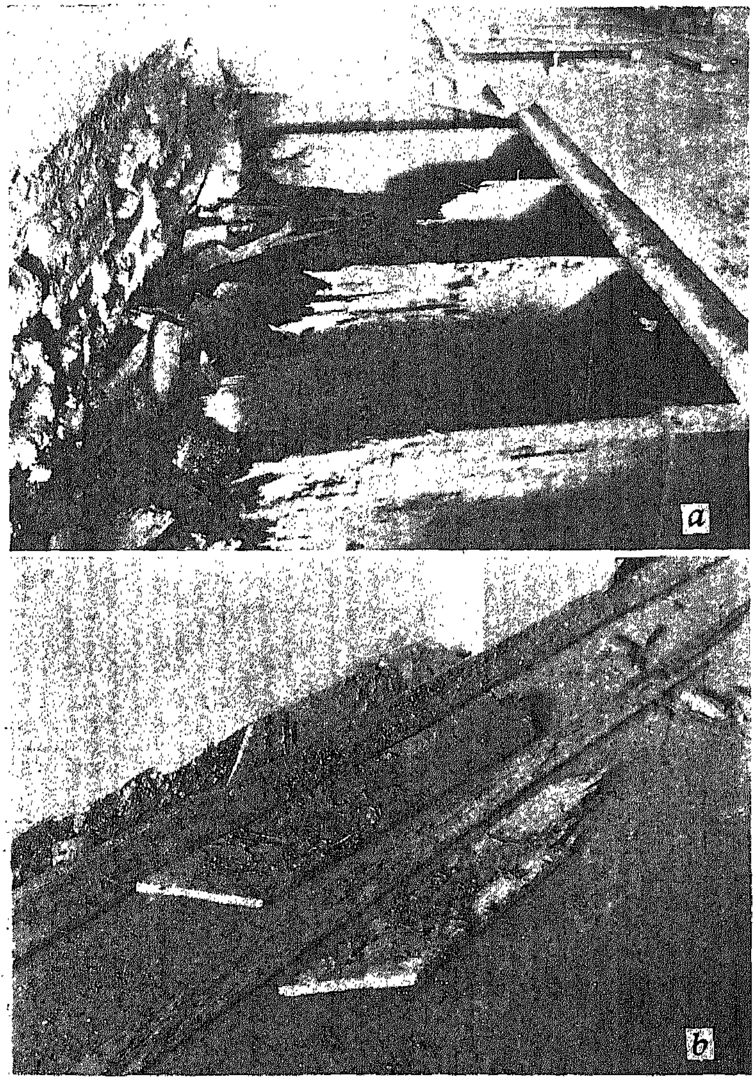


Fig. 55. Work of *Reticulitermes* in a building in Fresno, California. *a.* In joists. *b.* In flooring and subflooring. The joists were almost on the ground and placed in a masonry wall without proper ventilation.

one in the same block. Particular attention was paid to the causes of infestation and the cost of replacement.

The results of this survey are summarized in Table 5. More complete details for certain especially interesting cases are given on the pages following. While the exact nature and location of the damage in these houses were not recorded in all cases, they are given in Table 5 wherever available and significant. In evaluating the significance of the estimated cost of repair it should be noted that where the damage was to wood on the ground, no attempt was made to discriminate between termite and fungus damage, both of which were usually inextricably associated in such cases.

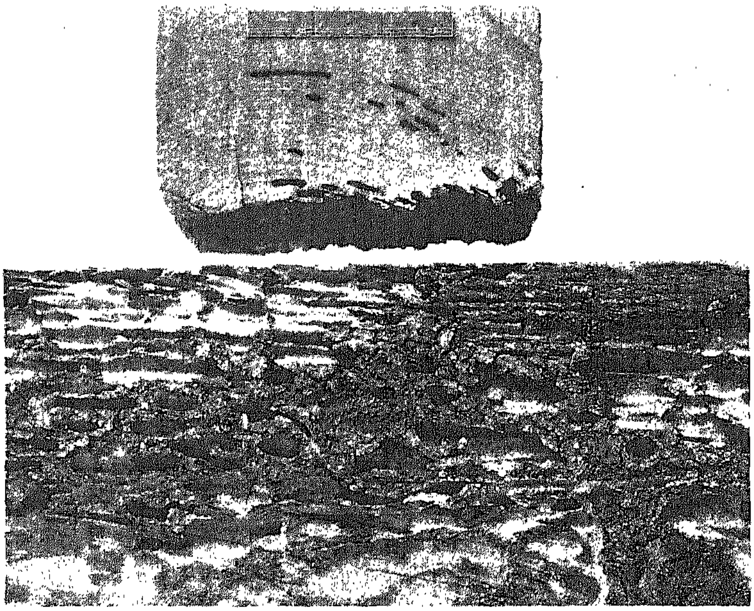


Fig. 56. Work of *Reticulitermes* in a mudsill of a house in Palo Alto, California. The bearing surface is enlarged in the lower photograph to show the characteristic frass and the surface attack where the wood was in contact with the ground. The cross section shows the sound condition of the wood and the relation of the internal galleries to annual rings.

Cases 1 and 2. These structures were of the garden cottage type one finds so often in northern California. Back of them and extending roughly across much of the length of the block was one of those heterogeneous fences that were to be found along the line representing the back boundaries of all the lots in the block. This one was so located with relation to the slope of the hill as to catch the washed-in earth from above, and in leveling and filling in more had been added. The result was that the wooden fence became an ideal incubator for termites. The two houses in question had been placed almost immediately against this fence, both with much of the wood in contact with the ground

TABLE 5

Case No.	Type of construction	Occupancy	Nature or cause of infestation	Estimated cost of repairs
1	Two-story wood frame	Dwelling	Exterior siding in contact with ground	$100
2	Two-story wood frame	Dwelling	Exterior siding in contact with ground	100
3	Wood frame	Dwelling	Wood steps and sills in contact with ground; insufficient ventilation	2,000
4	Stuccoed wood frame	Dwelling	Wood steps in contact with ground	120
5	Stuccoed wood frame	Dwelling	Inadequate foundation; steps and sills in contact with ground	75
6	Wood frame	Dwelling	Foundation too low	75
7	Wood frame	Dwelling	Foundation too low; studs, beams, and sills infested	500
8	Shingle exterior	Dwelling	Sub-floor sheathing infested	5
9	Wood frame	Dwelling	Basement floor joists in contact with ground; studs, sills, and joists infested	200
10	Wood frame	Dwelling	Soil banked up against exterior walls	25
11	Wood frame	Dwelling	Beams, studs, and steps infested; steps placed directly on ground	100
12	Wood frame	Dwelling	Concrete foundation level with ground; shrubbery close to building; joists, studs, and porch infested	400
13	Shingle exterior	Dwelling	Insufficient ventilation; wood in contact with ground	100
14			Soil in adjacent flower beds banked against exterior wall	75
15	Stuccoed wood frame	Apartment house	Basement floor of wood resting directly on concrete badly infested	300
16	Wood frame	Apartment house	No damage	
17		Dwelling	Exterior wood siding in contact with ground	200
18			Building had recently been repaired	
19		Sanitarium	Largest building in block; slight infestation in one post which was in contact with ground	25
20		Dwelling		Negligible
21			Steps and sills in contact with ground; slight infestation	25
22			Sills in contact with ground; infestation slight	50
23		Dwelling	Studs and joists in contact with ground; infestation extensive	200
24		Dwelling	Infestation in wood steps via old tree stumps	20
25			Wood in contact with ground	20
26			Wood in contact with ground	100
27			Wood in contact with ground	35
28			Soil in flower beds banked against exterior wood siding	100
29		Dwelling	Wood in contact with ground	40
30		Dwelling	No damage	
31			Wood in contact with ground	50
32			Wood in contact with ground	50
33	Wood frame; shingle exterior		Wood steps in contact with ground	20
34			Wood porch in contact with ground; infestation extensive	100
35	Wood frame; shingle exterior		Wood steps in contact with ground; infestation negligible	10

TABLE 5 *(Concluded)*

Case No.	Type of construction	Occupancy	Nature or cause of infestation	Estimated cost of repairs
36	....	....	Wood in contact with ground	$75
37	....	....	Porch and steps in contact with ground	75
38	....	....	Wood steps in contact with ground	20
39	....	....	No damage	....
40	....	....	Wood steps in contact with ground	15
41	....	....	Wood siding in contact with ground	50
42	....	....	Foundation too low; steps in contact with ground; infestation extensive	50
43	....	....	Foundation too low; steps in contact with ground; infestation extensive	200
44	Wood frame; shingle exterior	Dwelling	Infested tree stumps beneath house; porch too close to ground; infestation extensive	250
45	Wood frame; shingle exterior	Dwelling	Earth filled concrete porch; wood in contact with earth fill; studs, joists, and sills infested	100
46	Wood frame; shingle exterior	....	Wood steps in contact with ground; infestation slight	40
47	....	....	Steps and exterior siding in contact with ground	80
48	....	....	....	Negligible
49	....	....	....	Negligible
50	....	....	No damage	....

beneath. The termites were working as high as the second story in one of these small cottages and in both the damage was extensive, the estimated combined cost of replacement being $200.

Case 3. This large and well built dwelling was on brick foundations, and originally almost termite-proof. Inferior additions had been made and steps placed in contact with the ground. Part of the later addition was also in direct contact with the ground, the remainder on such a poor brick foundation that the bricks in the top tier had never had mortar or else had lost all the mortar. Furthermore, the addition had been built about an outside chimney, behind which the termites had built up to avail themselves of the heat, while in the triangular recess nearby plants were grown, providing the termites with moisture. This structure was only 33 feet from the two garden cottages (cases 1 and 2) and was probably once connected with the two by a board walk. The situation was an ideal one for termites, and, in addition, powder-post beetles had found lodging. The damage here was very extensive, the estimated cost of proper restoration being placed at $2,000.

Case 4. This was an ordinary large dwelling on low brick foundations, with a stucco front. Termite infestations were found only in the four sets of steps leading to the ground. One set in the rear had a bad air pocket, and had bred a severe case of fungus attack in nearby wood, although the steps were of concrete. Termites followed the fungus attack. Supporting timbers were found beneath another set of concrete steps and the carpenters had built into a badly infested piece of timber. The estimated cost of replacement was $120.

Case 7. This house had a very low brick foundation which appeared adequate except where the earth had been banked along one side of the house. Here the insects had attacked nearly every vertical stud, working from these into the supporting beams and sills. Here also the termites were active in the vicinity of the heated chimney. The cost of restoration was estimated by a contractor at $500.

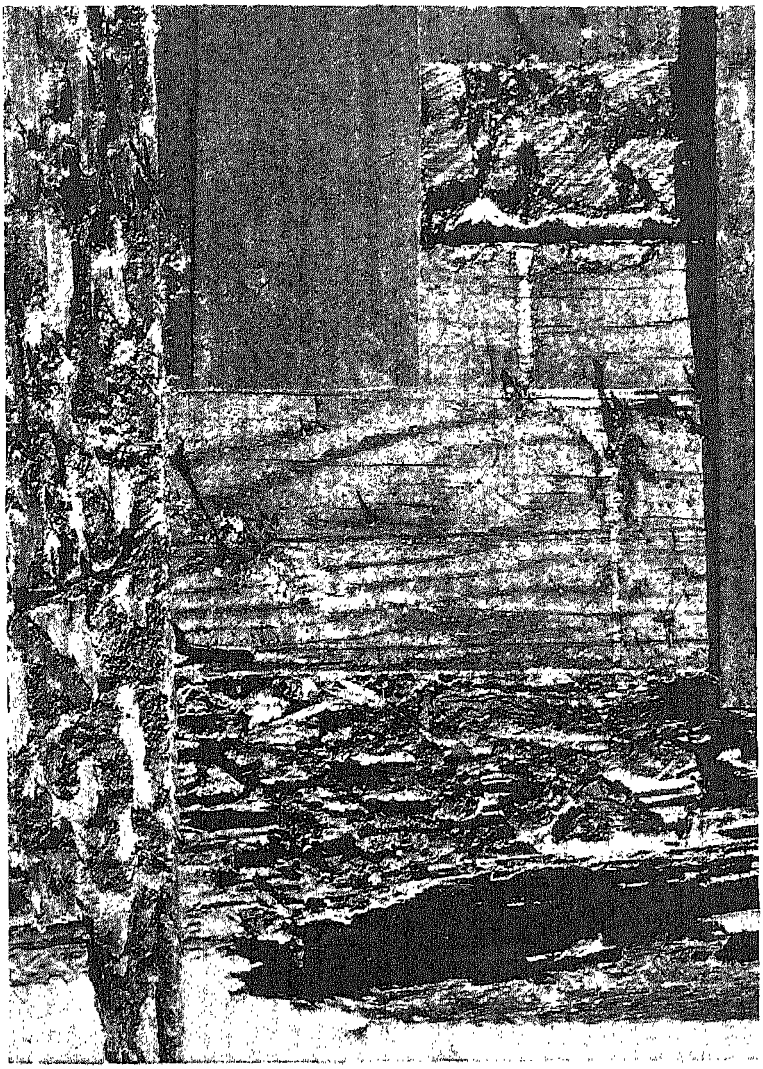


Fig. 57. Portion of the surface of a shingle-covered dwelling in Berkeley, California (case No. 13), after partial removal of shingles to show the surface attack on shingle-covered members and combined termite and fungus attack below.

Case 9. This was a large dwelling on a concrete and brick foundation 12 inches high. The basement floor was on the earth, however, and three or four rooms had been added as after-thoughts, and here again the earth came too close to the top of the foundations. One corner stud had been so eaten as to be ruined, and another had been penetrated and the soft grain eaten out, with damage to adjacent parts. The estimated cost of replacement was $200.

Case 12. This house had been built on concrete foundations brought just level with the top of the soil, a shallow basement being sunk a short distance into the ground, where a large modern heating furnace was installed. Flower beds were located along the side of the building, with the attendant moisture. The moisture, combined with the heat in the basement, made an ideal condition for termites, which migrated into the building from the damp soil outside, seriously damaging upright and horizontal beams. A porch was almost wrecked. Estimated cost of replacement, $400.

Case 13. This building was on brick and concrete foundations, but a shingled exterior had been permitted to extend over this to the ground. Extensive local infestation with both fungus and termites (fig. 57) followed. Augur holes and a cut-out square had been introduced in an effort to afford sufficient ventilation. The estimated cost of replacement was $100.

Case 15. While this large apartment building had concrete foundations, they were built in the form of walls for a shallow basement, and a wooden floor had been placed on the concrete floor of this basement. An extensive infestation had followed in the semi-subterranean rooms, some of the upright studs in the walls being badly attacked. The building was partly of stucco, which in too close contact to the ground affords dampness and protection highly valuable to subterranean termites. Estimated cost of replacement, $300.

Case 19. This was a large sanitarium on a good concrete foundation. The only damage found was in woodwork in the vicinity of a column of earth which had been left unexcavated in the process of shaping out the basement. Although it was perhaps the largest building in the block and had stood for over twenty years the damage could have been repaired for about $25.

Case 34. This building had a concrete foundation six inches above the ground which might have given protection, but at the rear a room and a cheap porch, which made ground contact, had been added to a very well constructed main building. Cost of replacement was estimated at $100.

Case 36. This building was in good condition, standing on a brick foundation, but was attacked at one point by both fungus and termites. At the point attacked there was a flourishing vine kept watered at the base, where falling leaves and other debris tended to build up a contact between the wood and the earth. Estimated cost of repair, $75.

Case 41. This building on a concrete foundation was attacked on the upper side where the earth was higher, and on the side facing the larger street, where flower beds were more common. On the lower side, where the earth level was below the weatherboard, no attack was noted, despite the presence on that side of a basement with a furnace.

CHAPTER 15

THE BARREN-LANDS SUBTERRANEAN TERMITE, *RETICULITERMES TIBIALIS*

BY

A. L. PICKENS

In the field the most reliable distinction between *Reticulitermes tibialis* and *R. hesperus*, the western subterranean termite, lies in the short, broad, and dark-colored head of the soldier of *R. tibialis*, as compared with the pale, long, and narrow head of the *R. hesperus* soldier (fig. 40*a–b*). Only by microscopic examination is one able always to distinguish between the workers of the two species. The reproductives are even more difficult to recognize, although on comparison *R. tibialis* is found to be a deeper black. To one trained in morphology there are other differences which mark the reproductives, such as the form of the eyes, but these are not readily seen and are subject to variation.

In California, as the map (fig. 42) shows, the distribution of *Reticulitermes tibialis* is largely complemental to that of *R. hesperus*. Its range in the United States includes the Great Basin and extends around the south end of the Rocky Mountains eastward across the prairies. In some places, as in the San Joaquin Valley of California, the two species occupy the same territory, but even here there is more or less local segregation in ranges, *R. hesperus* preferring cool, shaded, and moist spots, and *R. tibialis* open, sunny, and comparatively dry locations. The San Joaquin Valley appears at first sight as an isolated outlying portion of the range of *R. tibialis*, which extends not only from the eastern prairies to the western deserts, but also from the Pacific headwaters of western Montana southward to the southern portion of Lower California. However, on closer examination, we find a connecting link between the deserts of the Great Basin and the San Joaquin and Sacramento valleys through the Tehachapi Pass and the Feather River Valley, the upper reaches of the latter being dried to a desert condition by the desert winds flowing in above to take the place of the cooler air that flows into the warm Sacramento Valley below. This produces a suitable area for *R. tibialis* in the upper reaches, from which colonies have evidently made their way into the northeastern Sacramento Valley by drifting in flood times and lodging in suitable localities.

The chief biological distinction between the latter species and *R. hesperus* appears to lie in the ability of *Reticulitermes tibialis* to withstand more arid conditions. The life histories, even to the time for hatching of eggs, and the length of the various instars, appear to be about the same for both species. Although, when viewed over a large area, local variations in rain and temperature appear to produce differences in swarming times, in smaller areas where both species are within observing distance of each other, they are found to emerge at the same time and under very much the same conditions. Supplementary reproductives appear under the same conditions and in about the same length of time in *R. tibialis* as in *R. hesperus,* and the colonial habits show very little difference except in one important point. The barren-lands termite is much more pugnacious in fighting, as to both the soldier and the worker castes. In attacking an invading termite from an adjoining colony these termites have been known to destroy even members of their own colony which had become smeared with the juices of the enemy. Fighting among the secondary reproductives has been more frequent in *R. tibialis* than in *R. hesperus* colonies.

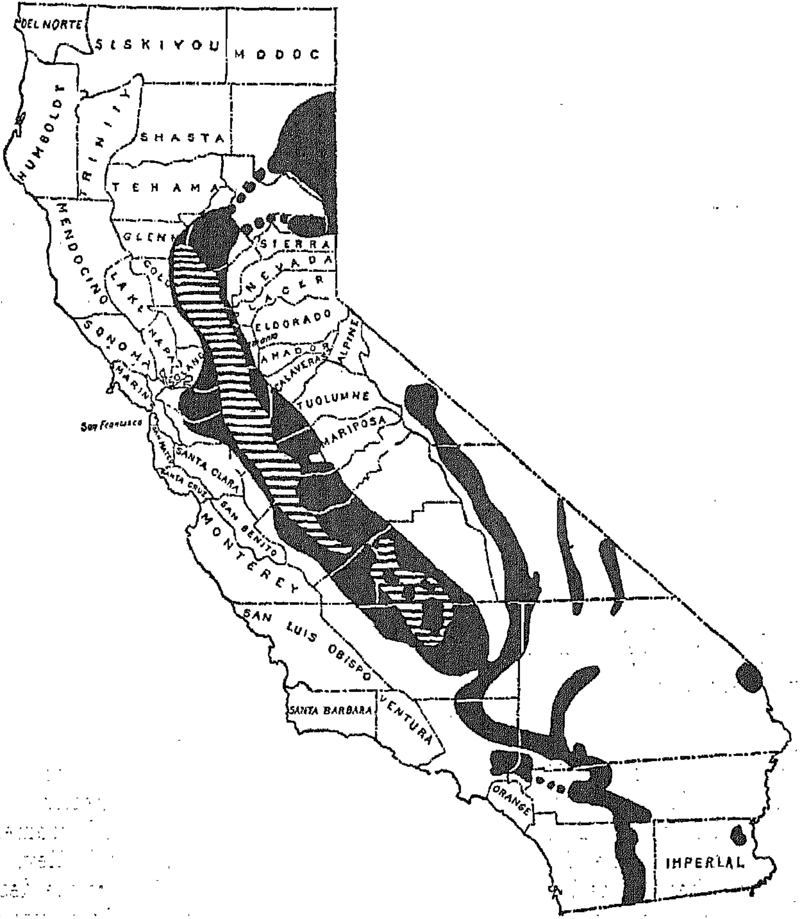


Fig. 58. Map showing in black the distribution in California of *Reticulitermes tibialis,* the barren-lands subterranean termite.

So nearly related are the two species that hybrids are fairly easy to secure by laboratory experimentation, five out of twenty pairs so mated producing young. The low rate of success may be explained by the difficulties of culturing under laboratory conditions, and by the extreme pugnacity of the barren-lands species, which is inclined to kill the milder tempered coastal form.

Economically considered, *Reticulitermes tibialis* is quite as capable of damaging woodwork as is *R. hesperus*. Statistically considered, it does much less harm, at least west of the Rockies, merely because it inhabits areas that are thinly populated; if more large cities were present in the semi-arid regions, the total damage done would probably rival that done by *R. hesperus*.

CHAPTER 16

AMERICAN SUBTERRANEAN TERMITES OTHER THAN THOSE OF THE PACIFIC COAST

BY

THOMAS E. SNYDER

Of the two types of termites, the dry-wood and the subterranean, the latter are by far the more injurious since, as a rule, they are more widespread (fig. 59), and since they are more liable to cause structural weakening.

There are 6,000,000 farms in the United States, and while damage by termites is not confined to the rural districts, it probably represents there a higher percentage of the total building valuation than in cities and towns where many of the buildings are constructed of stone, brick, or concrete, and where proper construction methods are more common. Termites are much more troublesome in the South, where it is warm. The United States has accordingly been divided, for statistical purposes, into a southern and a northern region, lying to the south and north, respectively, of a line drawn from Maryland to Nebraska. In the southern region thus set off farm buildings are valued at $2,900,000,000. It is estimated that the termites in this territory depreciate farm buildings approximately 1 per cent per year. This would mean an annual loss of $29,000,000 from termite attacks. But neither is the remainder of the country immune from termite attack. Illinois, Indiana, New York, and the other states all report damage by these insects (fig. 60). The total farm building valuation in this region is $8,141,000,000. Allowing a depreciation of 0.001 per cent, we have a loss of $8,141,000, or a total for both regions of $37,141,000.

Table 6 gives the number and the distribution by states of reports of termite damage which came into the U. S. Bureau of Entomology during the period from July 1, 1931 to July 1, 1932, and Table 7 gives the cases reported for the calendar year 1932, as distributed by region and month.

These reports represent a mere fraction of the cases actually discovered during the year 1931–1932, and these again are but a small fraction of those actually in existence. For example, it will be seen that there were sixty-eight such notices from California during the year, while for the nine and one-half months from November, 1930 to August 15, 1931 the reported cases of repair in Los Angeles County alone totalled 1,840, and these, of course, by no means represented the total cases of termite damage for that area and period. The number of such cases seems to be controlled by several factors, chiefly (1) altitude, (2) latitude (especially as temperature and humidity are concerned in these two factors), (3) population, (4) general education of the public, and

(5) activity of commercial termite control operators. Many investigations made by biologists of the Termite Investigations Committee in different cities and towns in California have shown that termites could be found in from 20 to 90 per cent of residences of the ordinary type or, if not in them, in some wooden structures on the premises, such as poles, posts, fences, walks, flower stakes, etc., etc.

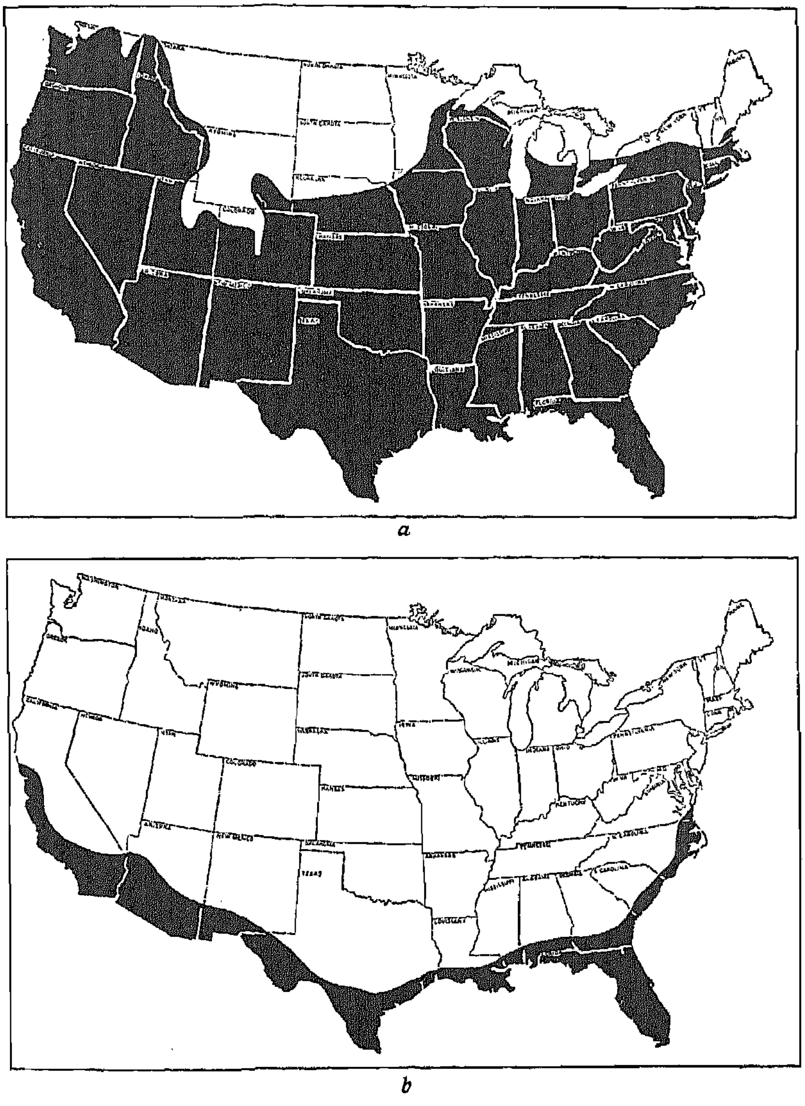


Fig. 59. *a*. Map showing in black the area of the United States subject to damage by subterranean termites. *b*. Map showing in black the area of the United States subject to damage by dry-wood termites.

TABLE 6

CASES OF DAMAGE BY TERMITES TO BUILDINGS IN THE UNITED STATES REPORTED TO THE U. S. BUREAU OF ENTOMOLOGY FROM JULY 1, 1931 TO JULY 1, 1932

State	July 1931	Aug.	Sept.	Oct.	Nov.	Dec.	Jan. 1932	Feb.	Mar.	April	May	June	Total cases for year
Alabama	7	6	11	4	2	7	1	3	6	6	7	3	63
Arizona	....	....	....	2	2	1	....	1	2	....	....	1	9
Arkansas	3	2	4	4	1	2	1	....	2	4	10	5	38
California	7	10	5	4	2	6	5	7	5	6	9	2	68
Colorado	....	....	....	1	....	....	....	....	....	....	....	....	1
Connecticut	2	1	2	....	....	1	1	....	1	4	2	1	15
District of Columbia	10	4	5	3	2	5	4	12	27	29	19	12	132
Florida	13	26	13	13	7	12	15	12	14	22	21	15	183
Georgia	6	6	6	2	5	2	8	6	6	9	14	8	78
Illinois	3	....	....	3	1	1	1	2	2	3	6	4	26
Indiana	....	....	3	3	1	1	....	....	5	4	1	4	22
Iowa	2	3	....	2	..	1	1	....	1	2	1	5	18
Kansas	1	1	1	1	1	1	2	....	....	1	....	2	11
Kentucky	....	3	....	7	3	2	1	1	2	8	4	5	30
Louisiana	3	8	4	4	2	1	1	3	4	7	2	3	42
Maryland	4	2	1	....	1	....	2	2	10	19	9	10	60
Massachusetts	2	5	....	....	....	....	1	2	1	1	....	4	16
Michigan	1	4	....	1	1	....	....	....	1	....	7	1	16
Mississippi	2	1	1	....	....	....	1	....	....	1	1	1	8
Missouri	9	3	5	2	2	3	6	1	3	17	13	13	77
Nebraska	1	....	....	....	....	....	....	2	....	1	1	1	6
New Jersey	1	2	2	1	....	1	....	2	2	5	3	2	21
New York	4	2	3	3	2	....	3	1	4	12	11	10	55
North Carolina	9	21	6	2	2	1	1	4	15	16	7	6	90
Ohio	2	4	3	2	....	1	1	3	8	18	11	3	56
Oklahoma	2	7	4	3	1	1	1	....	....	6	3	6	34
Oregon	....	....	....	2	....	....	....	....	....	1	1	....	4
Pennsylvania	2	4	4	2	2	1	1	4	11	6	11	5	53
South Carolina	4	6	6	2	3	....	2	4	3	8	11	5	54
Tennessee	11	7	7	6	2	5	2	3	3	11	12	4	73
Texas	8	22	8	8	7	4	8	5	10	11	8	7	100
Utah	1	....	....	1	....	....	....	....	....	....	....	....	2
Virginia	13	13	15	17	5	3	3	6	11	15	21	17	139
Washington	....	1	....	1	....	....	2	....	....	....	....	....	4
West Virginia	....	....	2	3	....	....	....	....	....	4	5	9	23
Wisconsin	....	1	1	....	....	1	....	....	....	....	2	....	5
Wyoming	....	....	....	1	1	....	....	....	....	....	....	....	2
Total cases per month	133	175	122	110	58	64	75	86	159	257	233	174	1,646

It has been found profitable to protect wooden buildings from termites by an additional investment of from 2 to 10 per cent; this means, over fifty years of depreciation, 0.04 to 0.2 per cent per annum. The higher figure represents the cost of protection from damage by dry-wood termites. However, in continental United States damage by the dry-wood termite is not known to be widespread or serious (fig. 59*b*), and the additional cost is therefore not warranted from the standpoint of protection against termites alone.

As pointed out, damage by subterranean termites is more common, widespread, and serious than that caused by the dry-wood type (figs. 59, 60). The former seek food and shelter in the structures of man, and as a result buildings and their contents, wooden poles, derricks, towers, posts, ties, and mine props are damaged. Minor local injury occurs to trees, shrubs, crops, and flowers. In eastern United States, as in the case of most of western United States, all such damage is caused by species of *Reticulitermes*.

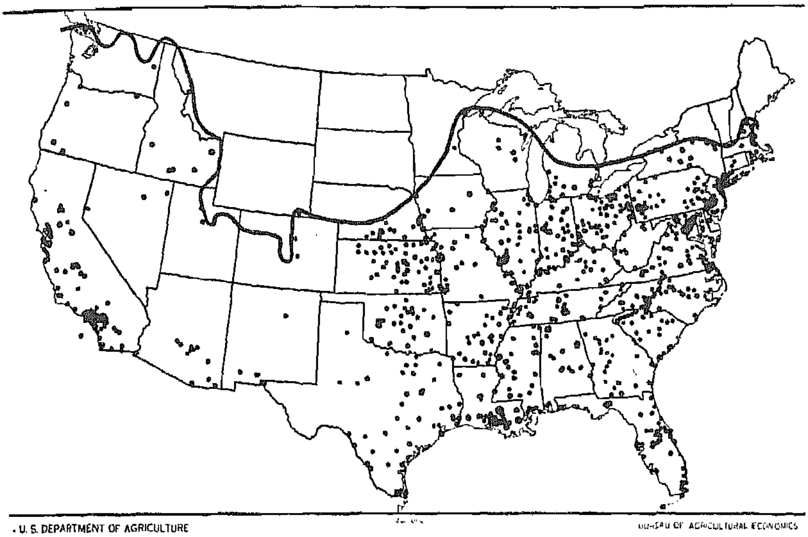

U. S. DEPARTMENT OF AGRICULTURE
BUREAU OF AGRICULTURAL ECONOMICS

Fig. 60. Map showing distribution of termite damage to buildings, as reported to the U. S. Department of Agriculture to July 31, 1931. This gives a rough idea of the distribution of such attacks in the area subject to damage, although the number reported is by no means always closely related to the number in existence (see p. 178).

TABLE 7

CASES OF INJURY TO BUILDINGS BY SUBTERRANEAN TERMITES REPORTED TO THE FEDERAL BUREAU DURING THE CALENDAR YEAR 1932, ARRANGED BY REGION AND MONTH

	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	
New England	2	2	2	5	2	5	5	4	....	3	....	....	30
Middle Atlantic	13	27	65	90	79	65	39	40	27	24	25	22	516
South Atlantic	10	26	38	55	53	34	23	29	14	21	9	19	331
East Central	10	6	18	33	22	16	9	12	7	5	8	6	152
North Central	....	1	....	....	9	1	2	1	3	....	2	3	22
West Central	4	3	4	20	15	21	11	9	16	14	12	12	141
Lower Mississippi	29	14	15	46	43	29	38	29	11	10	1	6	271
Southwest	....	1	12	....	....	1	2	....	11	12	4	3	46
Pacific	6	7	5	7	10	2	5	5	5	4	2	1	59
Total	74	87	159	256	233	174	134	129	94	93	63	72	1,568

The timber foundations of buildings, the bases of poles, posts, and props are structurally weakened by subterranean termites. Such damage to buildings is generally made possible by careless or improper construction. Since proper construction will, as a rule, prevent and remedy such injury, efforts have been made to have certain fundamental provisions inserted in the

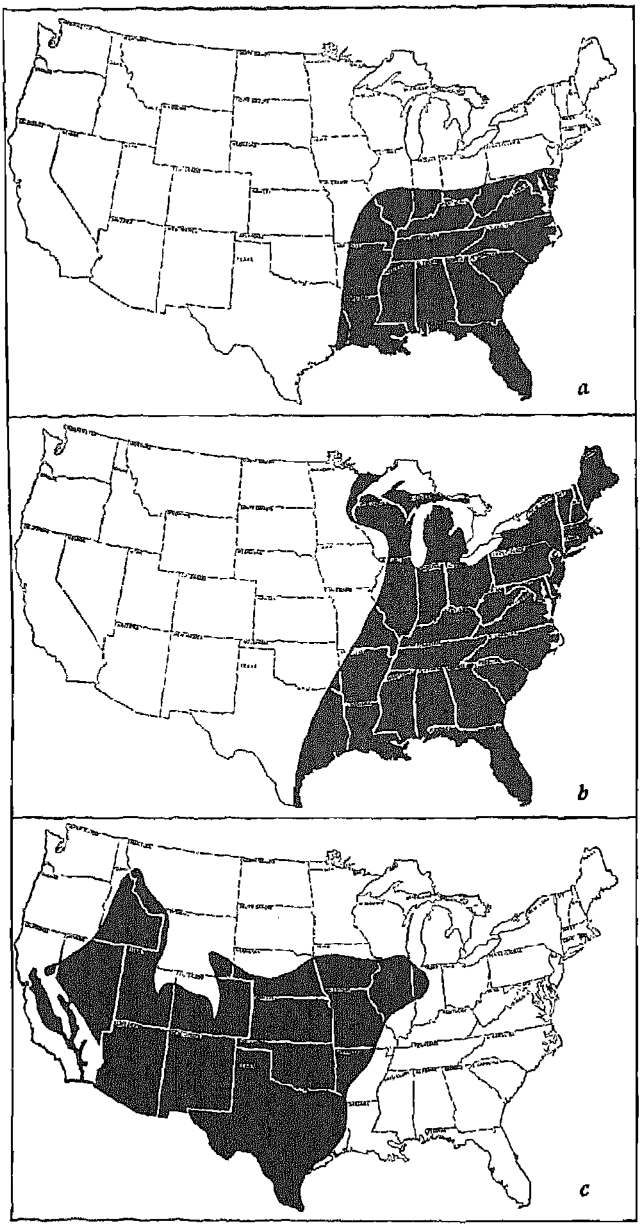


Fig. 61. Maps showing in black the distribution of the species of subterranean termites responsible for extensive damage in central and eastern United States. *a*. Area occupied by both *Reticulitermes hageni* and *R. virginicus*. *b*. Area occupied by *R. flavipes*. *c*. Area occupied by *R. tibialis*.

mandatory sections of city building codes to protect structures from termite attack (chap. 54). Portions of poles, posts, etc., in contact with the soil can be protected from subterranean termites by impregnation with standard chemical wood preservatives. Railroad ties in standard ballasted tracks where there is heavy traffic are not damaged by termites, probably because of the frequent vibration.

A list of the subterranean termites of eastern United States with their distributions will be found on page 122. Much careful comparative study is needed before a satisfactory key can be made for these various species. The composite map of distribution of the species of *Reticulitermes* (fig. 42) and the separate distribution maps given here will help in placing them.

Reticulitermes Flavipes (Kollar)

This termite plays the rôle in the eastern portion of the United States that *Reticulitermes tibialis* does in the West, *R. claripennis* and *R. humilis* in the Southwest, and *R. hesperus* on the Pacific Coast (fig. 61*b*). In addition, it occurs in Mexico and in certain localities along the Mediterranean in Europe, especially in southern France. This termite attacks and destroys the woodwork of buildings, materials stored therein (fig. 62), telegraph and telephone poles, fence posts, etc., and, occasionally, living trees, shrubbery, flowers and crops. It is a very destructive termite, since it weakens the foundations of buildings.

Swarming.—Diurnal swarming is usually the rule among termites of this genus. In America the colonizing flights of outdoor colonies of *Reticulitermes flavipes* occur in the early spring, during April or early May; swarms may also occur in autumn, in September, October, or November. Several (as many as four) swarms may occur from the same colony, over a period of about a month. The first swarm is the largest. Males and females occur in relatively equal numbers. Young and mature brachypterous (with wing pads) reproductive adults are found in fairly large numbers each year in the same colony with, usually, a very much greater number of macropterous (with wings) reproductive adults, but before the colonizing flight they disappear. Presumedly, they leave by means of subterranean tunnels to establish new colonies. Apterous (wingless) supplementary reproductives occur more rarely.

Incipient colonies are founded by dealated adults which burrow under pieces of decaying wood in or on the soil. Rarely do they utilize crevices in trees or logs, probably because of the less certain moisture supply. Young colonies established by brachypterous adults are to be found in similar locations. Whether crossing occurs between dealated and brachypterous reproductive types in *young* colonies is doubtful. It is certainly to be found in *old*, well established colonies.

Physogastric macropterous queens reach a maximum length of 14.5 mm. and a breadth of 4 mm.; brachypterous queens, a length of 12 mm.; apterous queens, a length of 7 mm. All forms were measured while living. When preserved in alcohol, a length of 16.5 mm. is the maximum for macropterous queens.

Macropterous reproductive adults probably head colonies more commonly, with brachypterous forms next in frequency, and apterous forms rarest. The latter two types are polygamous, and large numbers of queens occur with lesser numbers of males.

There is no definite permanent royal cell. The reproductive forms are usually found in the more protected inner, harder wood. If conditions are unfavorable, as in winter, they migrate through the soil or in galleries in wood to cells below the frost line. Occasionally, physogastric macropterous queens are found below ground in summer in the roots of trees; also, both macropterous and brachypterous reproductive forms are frequently found in the wood in the base of telegraph and telephone poles below the surface of the ground.

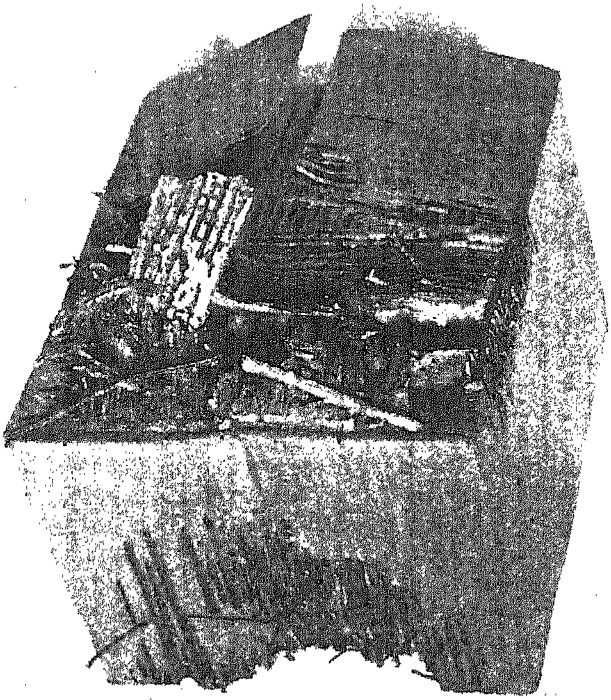


Fig. 62. Corrugated pasteboard box ruined by subterranean termites while in storage.

The rate of egg laying is slower in recently established colonies; six to twelve eggs comprise the first batch. The male and female continue to live together for life unless an accident intervenes. Workers and soldiers comprise the first brood. Reproductive forms are not produced in new colonies during the first year. Copulation occurs at irregular intervals and gradually the colony increases in size. In well established colonies thousands of eggs are to be found. Large colonies, while dispersed and difficult to estimate as to size, are known to contain hundreds of thousands of individuals. Very few data are available as to the relative proportions of the castes, but workers and macropterous forms usually predominate, according to the time of year.

Reticulitermes Hageni Banks and R. Virginicus Banks

These smaller, southern species are more restricted in distribution than is *Reticulitermes flavipes.* They are confined to the southeastern United States (fig. 61*a*). *R. hageni* is similar to *R. virginicus*, but the alate is a pale, yellowish-brown in color. In habits both are similar to *R. flavipes.*

Swarming.—Reticulitermes hageni swarms late in the season, usually from August to October. *R. virginicus* swarms as a rule about one month later than *R. flavipes,* namely, at the end of May or in June, depending on the season. Rarely, winged adults have been taken in November, so there may be an autumnal flight for *R. virginicus* as for *R. flavipes.*

In 1919 the writer observed maturely pigmented, brachypterous colonizing adults of *Reticulitermes virginicus* emerging from a stump during the swarm of the winged sexual adults. These brachypterous adults, it was believed, had inherited the instinct to fly or swarm from the period when all termites were winged; but having no wings they could only run about, and it was thought possible that this was the manner in which they emerged from the parent colony to establish new colonies.

It is now regarded more probable that brachypterous adults normally leave by subterranean passages, accompanied by workers and soldiers, since these forms must be fed by the workers in order to survive. Possibly those observed above were merely crowded out with the macropterous adults; they were in the parent colony unusually late in the year.

On April 25, 1925 the "pseudo-flight" of a few mature brachypterous adults of the same species of termite was again observed. These forms came from an infested building in Washington, D. C., during the swarm of winged adults at 3 p.m. This was the third swarm of winged adults from this building during the spring of 1925; previous swarms had occurred on April 11 and 14. A pseudo-flight, then, occasionally occurs in colonies, and may be a reversion manifested only by a few adults.

At Lake Toxaway, North Carolina, the writer found a colony under a stone on a mountain, headed by an apterous queen.

Reticulitermes Lucifugus Rossi

Confined to the vicinity of Forest Hills, Massachusetts, this termite of Mediterranean Europe may have been introduced into the United States.

Swarming.—The colonizing flight occurs one month later than that of *Reticulitermes flavipes.* In the vicinity of Boston, June and July are the months when the flight occurs. Physogastric macropterous queens and beetle termitophiles have been discovered near Boston in colonies of this European termite.

Reticulitermes Arenincola Goellner

The known distribution of this termite is the Chicago area, where it has been found under and in decaying pieces of wood in sandy places near the sand dunes. It has habits similar to *Reticulitermes tibialis* and occurs with this species in the Indiana sand dunes.

Swarming.—The colonizing flight occurs in the Chicago area during the last part of May.

Reticulitermes Tibialis Banks

This termite of western United States is probably the most widely distributed species of *Reticulitermes* in the United States (fig. 61*c*). It lives under the most varied conditions, and its ecology presents a fascinating study. In the Chicago area, in Nebraska, and in California it lives among sand dunes, infesting small pieces of wood partially buried in the sand, and making shelter tubes through the sand. In Colorado it occurs at high elevations on mountain sides (up to 7,000 feet elevation), and in Kansas and Texas it is to be found in heavily sodded prairies and in hard-baked and often alkali soil. It is also found in moist river bottom lands and along streams in canyons, but essentially it is a desert or prairie species.

Swarming.—Colonizing flights occur in both spring and summer. Brachypterous reproductive adults have been found in the roots of scrub oak below ground in the Garden of the Gods in Colorado. Apterous reproductive forms were found under a stone in the same locality.

Reticulitermes Claripennis Banks

This species of termite occurs in southwestern United States (fig. 42). It overlaps with *Reticulitermes tibialis* in the United States, but also occurs in Mexico, as does *R. flavipes.*

Swarming.—Colonizing flights occur in both spring and autumn.

Reticulitermes Humilis Banks

Found only in Arizona and Mexico (fig. 42), and recently in New Mexico, this termite occurs in both bottom lands and mountain regions, up to an elevation of at least 6,000 feet in the vicinity of Tucson, Arizona. It is often found in dry river bottom beds in drift wood.

Swarming.—The colonizing flights are late in June or July. A large physogastric macropterous queen was found in a colony under a stone in Madera Canyon, Santa Rita Mountains, Arizona (Banks and Snyder, 1920).

Chapter 17

THE DESERT SUBTERRANEAN TERMITE, *HETEROTERMES AUREUS*

BY

A. L. PICKENS AND S. F. LIGHT

The workers and soldiers of *Heterotermes aureus* are remarkably like those of *Reticulitermes*, as are their habits and the appearance of their workings. With care, the soldier of *Heterotermes* may be distinguished as having relatively longer and more slender mandibles than those of *Reticulitermes* (fig. 40). The reproductives, while similar in form and size to those of *Reticulitermes*, are very light in color, with transparent white wings and yellow or yellow-brown bodies, in contrast to the black of the *Reticulitermes* alate.

The covered ways and tubes of *Heterotermes* differ from those of *Reticulitermes* in being smaller and more nearly circular in section. The most noticeable difference in their workings as contrasted to those of *Reticulitermes* is the characteristically light yellow color of their fecal spottings and of the frass, which they produce in greater quantity than does *Reticulitermes*. The spots and frass of *Reticulitermes* are a dirty light brown in color.

Heterotermes aureus is the most northerly of the American species of *Heterotermes*. It is the only species of this genus found in the United States, and is confined to the Colorado and Gila deserts (fig. 63*a*). It ranges up the Colorado Valley to the north of the Chocolate Mountains in Riverside County, California, but appears to be absent from the Mohave Desert save at its southern and eastern edges. To the south it ranges at least as far as Mazatlan on the west coast of Mexico, and other closely related species are found ranging south from there at least as far as central Brazil.

H. aureus has not, so far, been found north of the range of ocotillo, and is a great consumer of the dead stalks of this plant, as also of the giant sahaura cactus. A. W. Keller found it in all but one of nearly a hundred dead sahauras examined in central Arizona.

The species of this genus have habits much like those of *Coptotermes* and not greatly different from those of *Reticulitermes*. They are, however, more truly subterranean than is *Reticulitermes*, the royal pair entering the earth directly and excavating the royal cell there; and they are much more active and persistent in building their covered ways and tubes over impenetrable materials to reach susceptible wood. They display a zeal in their work which probably arises from necessity, since a slow-moving termite near the desert surface would soon dry out to a fatal degree. Segregated colonies produce secondary reproductives in about six weeks, as does *Reticulitermes*.

Since their desert environment subjects *Heterotermes* to more rapid evaporation than is the case with *Reticulitermes,* their tubes and runways must be more nearly air-tight than those of *Reticulitermes.* They are typically much smaller, are much more solidly built, and tend more to a circular cross section, in contrast to the flattened runways of *Reticulitermes.* As their tubes advance, the openings are protected by soldiers keeping guard.

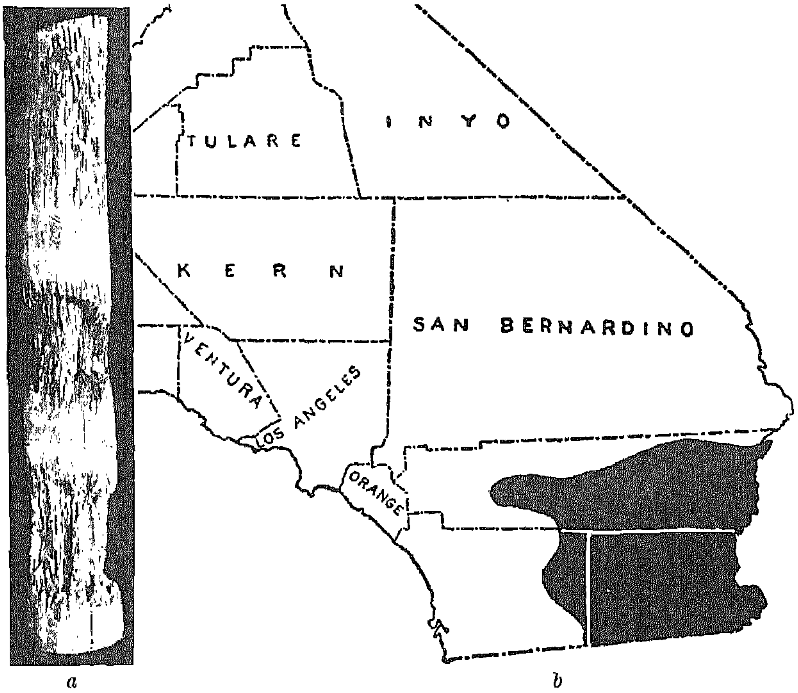


Fig. 63. *a.* Photograph of buried portion of a pole of lodgepole pine showing damage by *Heterotermes* in less than a year. The uninfested areas on the pole represent the positions of rings of treater dust (bag-house arsenic), which was ineffective, due to lack of moisture. Similar attacks are reported to have occurred for thirty miles in this pole line, located about forty miles north of Phoenix, Arizona, which was so badly damaged as to require replacement in less than a year. *b.* Map showing the distribution of *Heterotermes aureus* in California.

The workers are indefatigable toilers. When overlying sands are sufficiently cool, they plunge into them, and, loosening a grain at a time, open runways for their use. The walls of the wider portions of the tunnels are chinked and built up with material brought from the narrower and newly opened parts of the tunnel. Many of the particles are carefully placed and then forced into position by a shoving or ramming motion of the head, which is moved from side to side and pressed mouthward, while the grain is held by the insect's mouth parts. With time these arched tunnels become so lined with fecal plaster that they are very strong; frequently they are constructed along the lower sides of stones on the desert, and when such a stone is lifted, the runways adhere firmly to it.

There seems reason to believe that *Heterotermes* is favored by the advance of civilization into the desert. Irrigation brings more moisture, and artificially heated basements are quite as attractive to it as they are to *Reticulitermes hesperus*. The transportation of dead wood for fuel possibly leads to the distribution of *Heterotermes* into areas not previously inhabited.

Only the fact that *Heterotermes* is limited in distribution prevents it from being our most destructive termite. It is not so dependent on moisture and the attendant decay as is *Reticulitermes,* and it does serious damage to any sound, dry wood which it succeeds in connecting with its damper subterranean burrows. It penetrates even the Sonoran ironwood *(Olneya tesota),* which has a specific gravity of 1.15.

Its facility for building covered runways over impervious structures to reach wood renders protection of superstructures very difficult. It has shown a decided preference for hardwoods, particularly veneering oak. As is true of *Reticulitermes,* it is prone to be especially active where furnaces and fireplaces provide favorable temperature conditions. Thus, most of the reports of damage by this termite in Phoenix, Arizona, indicate it as especially active around fireplaces.

Heterotermes aureus has proved itself a serious menace to pole lines in certain areas of Arizona. In two reported instances it caused the failure (fig. 63*a*) of thirty and sixty miles, respectively, of lodgepole pine poles in from a year to fifteen months. In many other places in Arizona, and also in western Mexico, it has been found to do extensive and rapid damage to untreated poles. It seems probable that butt-treatment would largely eliminate these attacks. Species of this genus, however, have shown a propensity for attacking crossarms of susceptible wood, both in Mexico, near Mazatlan, and in western Arizona. This would seem to indicate the wisdom of full-length treatment or, at least, of careful painting of the gains and the attached surface of the crossarm.

Species of this genus are much more facile at building up to wooden structures than is *Reticulitermes*. Even in the more northerly parts of their range (southern California and Arizona) they usually build tubes from the ground underneath buildings. These are often twenty-four inches or more in height. Hence a greater ground clearance would be desirable in these regions, and either the use of pressure-treated wood for all exposed understructures, including mudsills, or, at least, as thorough a surface treatment as possible of such understructures. In the warmer parts of its range, as, for example, in Empalme de Guaymas, State of Sonora, Mexico, *Heterotermes* is found building covered ways over the exposed surfaces of concrete foundations to reach the wood of the building. Here the use of treated sills or the use of a termite shield (p. 318) would seem to be indicated.

CHAPTER 18

THE DESERT TERMITES OF THE GENUS *AMITERMES*

BY

S. F. LIGHT

The earth-dwelling termites so far considered include those of great economic importance. They all belong to the family Rhinotermitidae. Of considerable biological interest, although not known to be of economic importance except in isolated instances, are a number of species of ground-dwelling termites restricted largely to the deserts and arid lands and therefore designated desert termites. These belong to the genus *Amitermes* of the family Termitidae.

Twenty-eight American species of the genus *Amitermes* are known (Light, 1932*a*). Nineteen of these species occur in the southern border states, four in Mexico, two in Central America, and three in South America. With the exception of *A. brevicorniger*, which is the only known species of the subgenus *Synhamitermes*, they fall into two clearly defined groups, the subgenus *Amitermes* s. str. and the subgenus *Gnathamitermes* (Light, 1932*a*).

The subgenus *Gnathamitermes* includes the larger species. These are the most nearly representative desert types. The alates are large, usually over 13 mm. in length with the wings, and brown in color. The soldiers are marked by broad, low, flat heads with long, nearly straight mandibles (fig. 64). They build tubes of sand or earth over poles and desert shrubs, under cover of which they eat away only the thin outer weathered portion of large shrubs or poles, or entirely eat away smaller, dead shrubs, leaving the empty tubes (fig. 65) to puzzle the uninitiated. These tubes duplicate in detail every twig and excrescence of the shrub about which they were built. No species of this subgenus is known to attack structures. In certain parts of Texas one such species, the tube-building desert termite, *Amitermes (G.) tubiformans* (Buckley), is reported to do very considerable damage to grazing plants by covering them with its tubes and supposedly eating them—whether while the plant is still living or after it is killed by being shut off from air and light is unknown. Another species, *Amitermes acutus* Light, has been reported by Dr. Ralph H. Smith *(in litt.)*, of the Citrus Experiment Station at Riverside, as killing about 1 per cent of the trees in a citrus orchard in southern California by eating through the bark and thus girdling the tree under cover of their mud galleries. Aside from this, the species of the subgenus *Gnathamitermes* are not known to be of economic significance.

The numerous species of the subgenus *Amitermes* s. str. are less truly desert species and are usually found in or near washes and dry stream beds. Unlike the species of *Gnathamitermes*, they are not known to construct exposed galleries, and unlike them, they do eat wood beyond the weathered surface and are known on occasion to attack wooden structures, although in but few cases have they caused any considerable damage. In most cases they attack partly buried pieces of more or less decayed driftwood, attacking it usually from the outside under cover of a heavy coating (fig. 66*b*), often nearly an inch thick, composed of black or dark brown fecal deposits intermingled near the outer surface with soil fragments and covered externally with a layer of sand or soil. Their galleries within the wood are also lined with these characteristic fecal deposits (fig. 66*b*). While new wooden structures are not commonly attacked, pegs made of the sapwood of cedar poles seasoned by twenty years use in the desert, placed in sand at Coachella, California, and watered at long intervals, were attacked almost at once by two species, *A. emersoni* Light and *A. minimus* Light. The attack was confined to the surface and under cover of

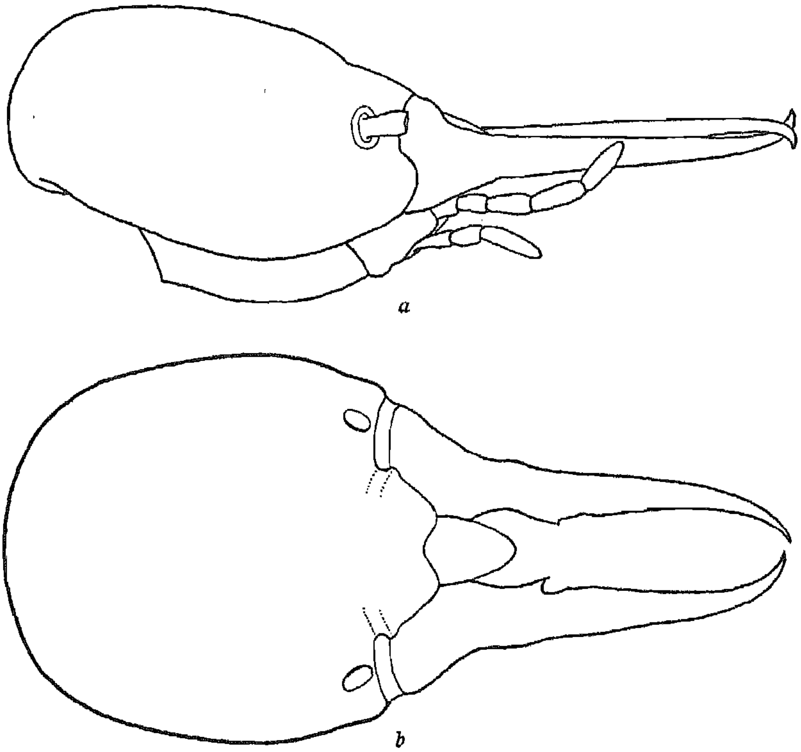


Fig. 64. Head of soldier of a common desert termite, *Amitermes (Gnathamitermes) acutus*. *a*. From the side. *b*. In dorsal view. × 38.

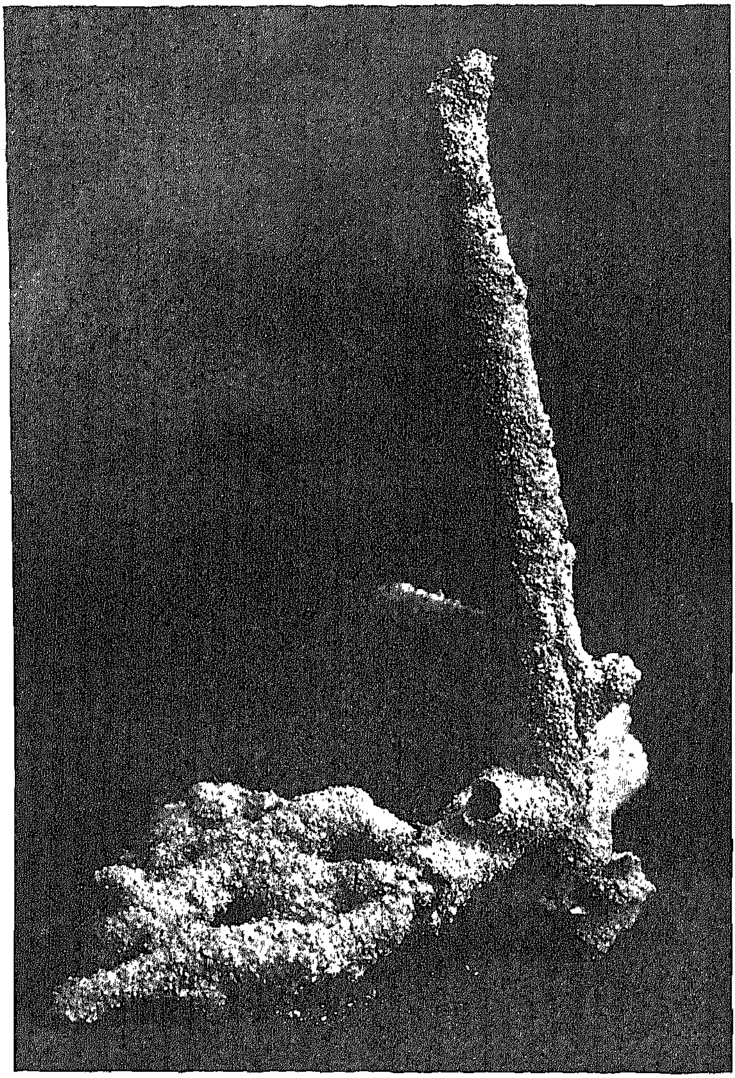


Fig. 65

Fig. 65. Earthen tubes built over desert plants by *Amitermes (Gnathamitermes)* sp. in California, and left as hollow tubes after the plant was eaten away. Natural size. From *Calif. Agr. Exp. Stn. Circ. 318, fig. 24.*

Fig. 66. Work done by desert termites in southeastern California, and photographs of heads and mandibles of soldiers.

a. Photograph of stakes of sound weathered sapwood from used poles set in sand at Coachella, California, showing surface workings of *Amitermes emersoni* and *A. minimus* after less than two months. *b.* Photograph of the workings of *Amitermes coachellae* in a piece of driftwood, showing the dark heavy frass characteristic of the workings of the

(Continued on page 198)

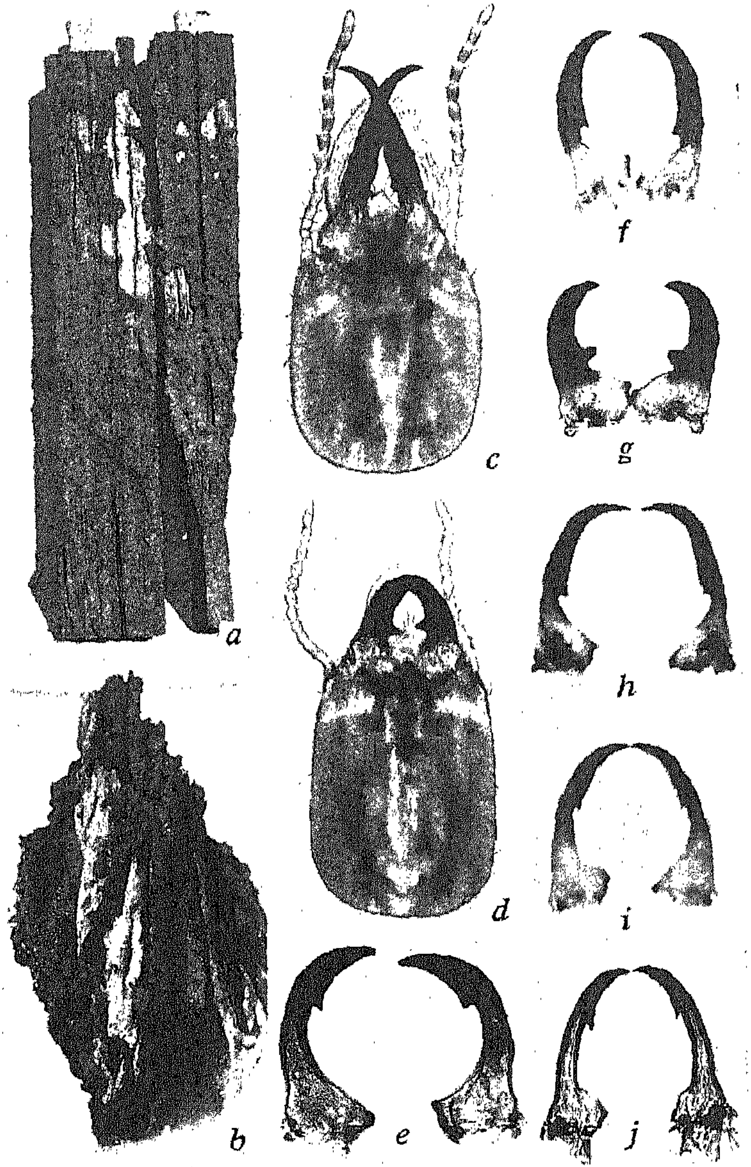


Fig. 66

Fig. 66—(Concluded from page 192)
species of the subgenus *Amitermes*. *c*. Head of soldier of *Amitermes (Gnathamitermes) acutus*. × 20. *d*. Head of soldier of *A.(A.) wheeleri*. × 34. *e–j*. Mandibles of the California species of the subgenus *Amitermes*. × 30. *e*. *A. snyderi*. *f*. *A. minimus*. *g*. *A. wheeleri* (= *A. californicus* Banks). *h*. *A. coachellae*. *i*. *A. silvestrianus*. *j*. *A. emersoni*.

a layer of cemented sand, with a thin inner layer of fecal deposits, as seen in figure 66*a*. No doubt, as the work progressed this layer would be thickened and, in time, as the decay spread in the wood, the workings would penetrate it.

The species of this genus are little known and many interesting problems of classification, distribution, habits, life cycle, and physiology remain to be solved. For a summary of our knowledge of the group see S. F. Light, *Contributions Toward a Revision of the American Species of the Genus Amitermes Silvestri,* published in the University of California Publications in Entomology, volume 5.

It will be seen that of the eighteen species found in the United States and listed below, the alates of four species and the soldiers of six are unknown as yet. Nests of the two latter groups of species are subterranean and have been reported but twice (Light, 1930*a*, 1931), and only once has the enlarged queen been taken.

The physiology of the species of the genus *Amitermes* remains almost entirely unknown. The intestine contains soil particles, large numbers of bacteria and a few Protozoa (Kirby, 1932*b*). The latter are small and few in number, and there seems no reason to believe that they function for the digestion of the cellulose, as is supposed to be the case with the species of the two lower families of termites. There remain the possibilities that the termites themselves secrete a cellulose-splitting enzyme, that they feed on fecal deposits which have been broken down by action of fungus or bacteria, or that they actually feed upon the fungus itself.

Following are a list of the species of the genus known to occur in the United States, with the general distribution of each, and a practical key to the species:

1. *Amitermes (Amitermes) coachellae* Light, southeastern California, southern Nevada, and southern Arizona
2. *A. (A.) emersoni* Light, southeastern California
3. *A. (A.) minimus* Light, southeastern California, southern Nevada, Arizona, and Texas (to extreme southeastern tip)
4. *A. (A.) pallidus* Light, southern Arizona; soldier unknown
5. *A. (A.) parvipunctus* Light, Texas; soldier unknown
6. *A. (A.) parvulus* Light, southern Arizona; soldier unknown
7. *A. (A.) silvestrianus* Light, Coachella Valley, southeastern California
8. *A. (A.) snyderi* Light, southeastern California; alate unknown
9. *A. (A.) spadix* Light, Texas; soldier unknown
10. *A. (A.) wheeleri* (Desneux), southeastern California, southern Nevada, Arizona, Texas (to extreme southeastern tip), western Mexico (at least as far south as Colima, Col.)
11. *A. (Gnathamitermes) acrognathus* Light, Texas
12. *A. (G.) acutus* Light, southeastern California, southern Nevada, Arizona; alate unknown
13. *A. (G.) confusus* Banks, Arizona and Texas; soldier unknown
14. *A. (G.) fuscus* Light, southeastern California; soldier unknown
15. *A. (G.) infumatus* Light, western Mexico, southeastern California; alate unknown
16. *A. (G.) magnoculus* Light, southeastern California; soldier unknown
17. *A. (G.) perplexus* Banks, southeastern California, Arizona, and Texas
18. *A. (G.) tubiformans* Buckley, Arizona and Texas; alate unknown

KEY TO THE SPECIES OF *AMITERMES* FOUND IN THE UNITED STATES

ALATES

A. Less than 12 mm. long with wings; head less than 1.10 mm. wide........Subgenus *Amitermes* s. str.
B. More than 13 mm. long with wings; head more than 1.10 mm. wide........Subgenus *Gnathamitermes*

A. Subgenus *Amitermes* s. str.

1. Black or blackish........2
1. Yellow to dark brown........4
2. Larger, head more than 1.05 mm. wide; black; pronotum clearly more than twice as wide as long........3
2. Smaller, head less than 0.95 mm. wide; dull grey-black; pronotum clearly less than twice as broad as long........*Amitermes minimus* Light
3. Very dark shining black; muscle markings of head hardly visible; fontanel more than half as wide as long........*Amitermes emersoni* Light
3. Smoky black; muscle markings visible; fontanel less than half as wide as long; postclypeus with a few light spots marking location of large hairs........*Amitermes coachellae* Light
4. Light; yellow below, light brown or yellow above........5
4. Darker; brown to light brown below, brown above........6
5. Very light; abdominal tergites yellow; fontanel broad; head more than 0.95 mm. wide........*Amitermes pallidus* Light
5. Darker above; abdominal tergites light brown; fontanel narrow; very small, head less than 0.90 mm. wide........*Amitermes parvulus* Light
6. Larger, head wider than 1.05 mm........*Amitermes silvestrianus* Light
6. Smaller, head less than 1.00 mm. wide........7
7. Fontanel very small........*Amitermes parvipunctus* Light
7. Fontanel large........8
8. Fontanel long and narrow; venter pale........*Amitermes wheeleri* (Desneux) (=*A. californicus* Banks)
8. Fontanel broad, pointed at the ends; venter brown........*Amitermes spadix* Light

B. Subgenus *Gnathamitermes*

1. Small, head width through the eyes 1.15 mm. or less; head narrow; ocellus separated from eye by its long diameter........*Amitermes acrognathus* Light
1. Large, head more than 1.20 mm. wide through the eyes; head broad........2
2. Eyes and ocelli of medium size; eye separated from posterior margin of head by twice its long diameter or more........3
2. Eyes and ocelli large; eye separated from posterior margin of head by less than twice its long diameter........*Amitermes magnoculus* Light
3. Dark brown........4
3. Light brown; fontanel and muscle markings distinct........*Amitermes confusus* Banks
4. Smoky brown; fontanel conspicuous, triangular; muscle markings conspicuous........*Amitermes fuscus* Light
4. Shining mahogany brown; fontanel and muscle markings obscure........*Amitermes perplexus* Banks

SOLDIERS

A. Head usually considerably longer than broad; antennae not conspicuously darkened distally; mandibles usually much shorter than the head and curved throughout; teeth large, or directed backwards, or distally located (fig. 66*d–j*)...............Subgenus *Amitermes* s. str.

B. Head nearly as broad as long; antennae conspicuously darkened distally; mandibles straight or nearly straight save at tips, as long or nearly as long as head (fig. 66*c*)...............Subgenus *Gnathamitermes*

A. Subgenus *Amitermes* s. str.

1. Teeth in distal half of mandibles (fig. 66*e*, *i*, *j*)............... 2
1. Teeth near base of mandibles (fig. 66*f–h*)............... 4
2. Mandibles massive, rugged (fig. 66*e*)...............*Amitermes snyderi* Light
2. Mandibles slender, smooth (fig. 66*j*)............... 3
3. Teeth near middle of mandible (fig. 66*i*)...............*Amitermes silvestrianus* Light
3. Teeth in distal one third (fig. 66*j*)...............*Amitermes emersoni* Light
4. Teeth large, cone-shaped, projecting inward (fig. 66*g*)...............*Amitermes wheeleri* Desneux
4. Teeth projecting but little, shelf-like, set off from basal hump by deep notch (fig. 66*f*)............... 5
5. Smaller, head less than a millimeter in diameter...............*Amitermes minimus* Light
5. Larger, head more than a millimeter in diameter...............*Amitermes coachellae* Light

B. Subgenus *Gnathamitermes*

1. Teeth below middle of mandibles of various types but not shelf-like (fig. 64*b*)............... 2
1. Teeth at middle of mandible; both shelf-like...............*Amitermes tubiformans* Buckley
2. Mandibles sharply narrowed at tooth level, very slender distally; teeth but little below middle; neither tooth in a notch...............*Amitermes aerognathus* Light
2. Mandibles not especially narrowed at tooth level, teeth considerably below middle; right tooth, at least, in a notch............... 3
3. Mandibles not longer than head, distally dark smoky red, tips markedly inbent. Head of worker smoky...............*Amitermes infumatus* Light
3. Mandibles as long as or longer than head, not distally smoky, tips not strongly inbent. Head of worker yellow............... 4
4. Sides of head strongly convex; head distinctly broadened in front of middle; mandibles strongly contracted near base with a distinct convexity just below tooth on each mandible; right tooth acute, distally directed...............*Amitermes acutus* Light
4. Head subrectangular, sides faintly convex; mandibles much less strongly contracted basally; tooth less acute, directed inward...............*Amitermes perplexus* Banks

CHAPTER 19

DRY-WOOD TERMITES, THEIR CLASSIFICATION AND DISTRIBUTION

BY

S. F. LIGHT

Dry-wood termites occur throughout all the tropics and the subtropics, and a few species extend into the warmer temperate regions. They belong to the family Kalotermitidae, whose species are with one exception wood-dwellers, and largely to the various subgenera of the large genus *Kalotermes*. The species of this family have habits varying with their moisture requirements. Some live in dry, sound wood; some live in the dead wood of living trees, apparently depending upon moisture from the living portions; some live in damp, buried wood; and at least one related species, *Paraneotermes simplicicornis* Banks, has adopted a semi-subterranean habit (see discussion in chapter 25). Those species which live in dry wood, or, at least, in wood not especially moist, are spoken of collectively as dry-wood termites. They include the species of most of the subgenera of *Kalotermes* and the genus *Cryptotermes*. Those of greatest known economic importance belong to the genus *Cryptotermes*, the subgenera *Kalotermes* and *Neotermes*, named in the order of increasing moisture requirements.

Powder-post termites.—These are smaller species constituting the genus *Cryptotermes* and several subgenera of the large genus *Kalotermes*, particularly *Lobitermes*, *Calcaritermes*, etc. They are confined to the warm tropics and are capable of developing colonies in small pieces of dry wood. Their presence is usually indicated by piles of tiny fecal pellets thrown out from their workings, and this has given them their common name. They are easily distinguished from other species of the genus *Kalotermes* by (1) the small size of their pellets; (2) the small size of all castes of the colony; (3) the fact that the soldier has a short, high, strongly truncated head, often excavated in front and usually black or dark brown in color; and (4) the fact that the alate in most species has the median vein of the wing curving forward to join the radius sector.

The colonies, while usually small, are numerous, and in heavily infested areas the evidences of their attacks are to be seen on every hand in furniture, in isolated boards, and in timbers of houses. They are the true "house termites" and are found in great numbers in wooden structures, even when absent or very rare in natural wood.

Cryptotermes brevis, the common powder-post termite, is the most important species of this habitat group. It ranges through the West Indies, Mexico, Central America, and South America at least as far south as Kartabo in

British Guiana. It has been reported (see chap. 23) in Florida, where it has probably been introduced. A very similar, if not identical species, *Cryptotermes pseudobrevis,* has been reported from South Africa (Fuller, 1921).

Where abundant, *Cryptotermes brevis* is responsible for a great deal of damage. Its colonies are commonly found in shelves of stores, where they often eat into books, stationery, drygoods, etc. A single small drygoods establishment in Colima, Mexico, reports an annual damage of about $500 from this species, which was found riddling drygoods and books, and was reported to have destroyed books left on the counter over night.

Various other species of this habitat type are responsible for damage to houses and furniture in different parts of the tropics. Among those of economic importance are *Cryptotermes piceatus* Snyder in Hawaii, *Cr. cynocephalus* Light and *Cr. (Planocryptotermes) nocens* Light in the Philippines, and *Cr. domesticus* Haviland in Malaysia.

The dry-wood termites proper belong to the subgenus *Kalotermes* s. str. Several species are of economic importance in North America, chiefly *K. minor* Hagen, *K. hubbardi* Banks, *K. marginipennis* Latreille, and *K. snyderi* Light, whose distribution is given in the list below. These and other species occurring in the United States are discussed later (chaps. 20–23).

The species of the subgenus *Neotermes* are not known to attack wooden structures, but are commonly of economic importance through their attacks on the hearts of living shrubs and trees, such as tea, coffee, etc. Among those whose attacks on cultivated plants are of importance are *Kalotermes (Neotermes) tectonae* Dammerman, which attacks the teak plantings in Java (Kalshoven, 1930), and *K. (N.) greeni* Holmgren, which attacks the tea plant in Ceylon (Jepson, 1927).

KNOWN DISTRIBUTION OF ECONOMICALLY IMPORTANT DRY-WOOD TERMITES

I. Powder-Post Termites
    - *Cryptotermes brevis* (Walker), Florida, Mexico, West Indies, Central America, and South America at least as far south as British Guiana
    - *Cryptotermes piceatus* Snyder, Hawaii and the Marquesas
    - *Cryptotermes cynocephalus* Light, Philippine Islands
    - *Cryptotermes (Planocryptotermes) nocens* Light, Philippine Islands
    - *Cryptotermes domesticus* Haviland, Malay States and Malay Archipelago

II. Dry-Wood Termites proper
    - *Kalotermes hubbardi* Banks, Arizona, Western Mexico
    - *Kalotermes marginipennis* Latreille, at higher altitudes in Mexico
    - *Kalotermes minor* Hagen, California, Arizona, northwestern Mexico
    - *Kalotermes snyderi* Light (= *K. marginipennis* Banks and Snyder), Atlantic Coast, Gulf States, Mexico, and Central America

KEY TO THE DRY-WOOD TERMITES OF THE UNITED STATES

ALATES

1. Smaller, less than 11 mm. to tip of wings; median weakly chitinized, bending forward to join radius sector near or beyond middle (subgenus *Cryptotermes*).... 2
1. Larger, 12 mm. to tip of wings, median not joining radius sector.... 3
2. Larger, more than 10 mm. long with wings....*Cryptotermes brevis* (Walker)
2. Smaller, 9 mm. or less in length with wings....*Cryptotermes cavifrons* Banks
3. Median midway between radius sector and cubitus (*Kalotermes* s. str.).... 4
3. Median near radius sector.... 12
4. Head less than 2 mm. wide.... 5
4. Head more than 2.1 mm. wide; eyes very large....*Kalotermes occidentis* Walker
5. Larger, more than 15 mm. long with wings.... 6
5. Smaller, less than 14 mm. long with wings.... 8
6. Body with long hairs.... 7
6. Body with only very short fine hairs....*Kalotermes jouteli* Banks
7. Smaller, 15 to 16 mm. long with wings....*Kalotermes schwarzi* Banks
7. Larger, more than 18 mm. long with wings....*Kalotermes marginipennis* Latreille
8. Body yellow to castaneous; wings light.... 9
8. Body nearly black; wings dark....*Kalotermes minor* Hagen
9. Less than 13 mm. long with wings.... 10
9. 13–14 mm. long with wings....*Kalotermes hubbardi* Banks
10. Less than 11 mm. long with wings.... 11
10. 11–12 mm. long with wings....*Kalotermes snyderi* Light (= *K. marginipennis* Banks)
11. Wings pale (western Arizona)....*Kalotermes banksi* Snyder
11. Wings blackish (eastern Arizona)....*Kalotermes approximatus* Snyder
12. Pale species, more than 14 mm. long with wings; antennae of 16 segments; cubitus showing no tendency to distal union with radius sector *(Neotermes)*.... 13
12. Dark brown; less than 12 mm. long with wings; antennae of 14 segments; cubitus tending to distal union with radius sector....*Paraneotermes simplicicornis* Banks (= *Cryptotermes infumatus* Banks)
13. Diameter of eye less than 0.36 mm. *Kalotermes (Neotermes) angustoculus* Snyder
13. Diameter of eye more than 0.44 mm....*Kalotermes (N.) castaneus* Burmeister

SOLDIERS

1. Head short, high, strongly truncate, smoky brown to black; mandibles reduced *(Cryptotermes)*.... 2
1. Head normal, red, reddish-brown or castaneous; mandibles large.... 3
2. Head greatly roughened above....*Cryptotermes brevis* Walker
2. Head smooth above....*Cryptotermes cavifrons* Banks
3. Pronotum very short, much less than one half as long as wide *(Neotermes)*.... 4
3. Pronotum about one half as wide or wider.... 5
4. Mandibles nearly as long as width of heads, tips sharp....*Kalotermes (Neotermes) angustoculus* Snyder
4. Mandibles heavy, much shorter than width of head, tips blunt....*Kalotermes (Neotermes) castaneus* Burmeister

5. Mandibles as long as head width or nearly so; usually heavy throughout; left mandible usually with three teeth; first two not elongated nor distally directed (*Kalotermes* s. str.) 6

5. Mandibles short, much shorter than head width; basally very thick, distally slender; left mandible with four teeth, first two long and distally directed .... *Paraneotermes simplicicornis* Banks

6. Head subrectangular, longer than wide, never more than 3 mm. wide 7

6. Head with rounded sides, about as long as wide, usually more than 4 mm. wide .... *Kalotermes occidentis* Walker

7. Third antennal segment at least as long as next three segments together 8

7. Third antennal segment not so long as next three segments together 12

8. Third antennal segment shorter than all remaining segments together 9

8. Third antennal segment as long as all remaining segments together .... *Kalotermes hubbardi* Banks

9. Anterior margin of pronotum serrate 10

9. Anterior margin of pronotum smooth 11

10. Pronotum very deeply emarginate in front; antero-lateral corners sharp; with a conspicuous tubercle on antero-lateral margin of dorsal surface of head .... *Kalotermes marginipennis* Latreille

10. Pronotum less deeply emarginate; antero-lateral corners rounded; without tubercle .... *Kalotermes texanus* Banks

11. Head reddish-brown; pronotum with high, sharp antero-lateral corners and straight posterior margin .... *Kalotermes minor* Hagen

11. Head light yellow-brown; pronotum with low, rounded antero-lateral corners and concave posterior margin .... *Kalotermes arizonensis* Snyder

12. Small; head yellow brown; pronotum much narrower than head; deeply and roundly excavate .... *Kalotermes lighti* Snyder

12. Larger; head reddish; pronotum at least as wide as head 13

13. Third segment of antennae longer than next two together .... *Kalotermes schwarzi* Banks

13. Third segment about as long as next two together 14

14. Large, 9–13 mm. long; eyes black; antennae of as many as 18 segments .... *Kalotermes jouteli* Banks

14. Smaller, 7–8 mm. long; eyes hyaline; antennae of 12 or 13 segments 15

15. Lateral anterior border of pronotum dentate .... *Kalotermes snyderi* Light

15. Lateral anterior border of pronotum smooth .... *Kalotermes approximatus* Snyder

CHAPTER 20

THE DISTRIBUTION AND BIOLOGY OF THE COMMON DRY-WOOD TERMITE, *KALOTERMES MINOR*

I. DISTRIBUTION AND MEANS OF IDENTIFICATION

BY

S. F. LIGHT

Distribution.—*Kalotermes minor* Hagen, the common dry-wood termite, is confined to western North America, chiefly to California, Arizona, and northern Mexico (fig. 67). It has, nevertheless, the greatest known range, and is by far the most destructive of the American species of wood-dwelling termites, and is probably unrivalled in either range or actual amount of damage done by any single wood-dwelling species anywhere in the world. Furthermore, due to the investigations of this Committee, it is the best known American dry-wood species, and has been chosen here as a type of that group.

Kalotermes minor ranges as far north as Tacoma, Washington, and is present in considerable numbers from northern California (northern Mendocino County and Lassen County) southward to the tip of Lower California, eastward at least as far as eastern Arizona, and southward along the coast of the Mexican mainland, the most southerly record on the mainland being at Guaymas. In the arid portions of its range it is confined largely to the canyons of the mountains and higher desert margins, being replaced in the lower, hotter, and drier areas by the southern dry-wood termite, *K. hubbardi.* In certain areas intermediate in altitude, such as Tucson and Ray, Arizona, these two species are found in the same territory, often in the same log, together with *Paraneotermes simplicicornis* Banks, the desert damp-wood termite (chap. 25). In localities at lower altitudes, such as Phoenix, Arizona, *K. minor* has not been found, while *K. hubbardi* abounds. At higher elevations, such as Ash Fork, Prescott, and Nogales, Arizona, *K. minor* is the only dry-wood termite, as is the case in California, except for a slight overlapping of its range with that of *K. hubbardi* at one point along the Colorado River.

In the more northerly portion of its range *Kalotermes minor* has a discontinuous distribution, being limited to certain warmer areas and absent or rare elsewhere. For example, in the cold fog belt included in the San Francisco Bay region it is absent, but it appears in Richmond, San Leandro, and the towns along the Sacramento River, as also on the Marin County side and on the peninsula south of San Francisco. In Mendocino County, California, it is abundant along the coast, seemingly rare or lacking on the outer coast ranges, but present in small numbers along the lower streams.

Location of colonies of Kalotermes minor.—This termite infests only sound wood and cannot long exist in decayed wood. In its natural habitat it is found in dead branches, stubs of living trees, stumps, and occasionally in logs, chiefly along streams or in canyons, and along the forest edge. In dry locations it is found occasionally in dead branches on the ground. It has been taken in most of our common trees, including sycamore, oak, alder, Monterey cypress, redwood, California laurel, buckeye, eucalyptus, willow, peach, pear, almond, cherry, etc., and probably occurs in the sound dead wood of the others where exposed to infestation.

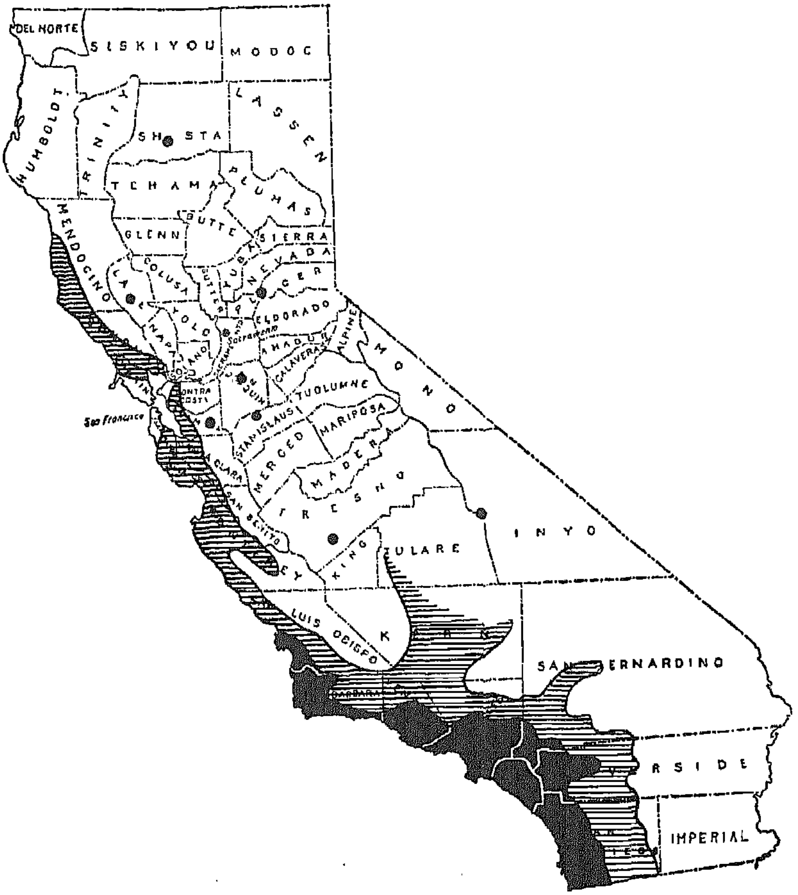


Fig. 67. Map showing distribution of *Kalotermes minor* in California. Areas of abundance are shown in solid black. Areas of less abundance are cross-hatched. Heavy dots represent isolated occurrences.

In the drier portions of its range, *Kalotermes minor* is commonly found in the dead or partly dead roots of sycamore and cottonwoods. Pieces of driftwood in the washes of the desert rim are often heavily infested. Colonizing swarms from these logs infest nearby desert shrubs. Such colonies are plainly out of place and show the results of their maladjustment in dwarfism and other abnormalities among their members. Although this species is typically an above-ground termite, it shows a further adjustment to the great extremes of desert temperature by living in progressively lower levels until, on the extreme margin of its range, it is seldom found above ground and confines itself chiefly to subterranean portions of poles, posts, roots, stumps, and driftwood.

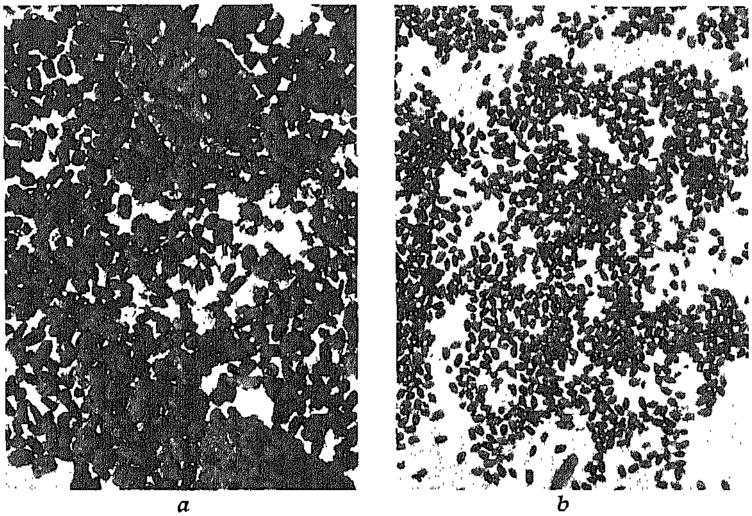


Fig. 68. Tiny impressed fecal pellets always present in the workings of the wood-dwelling termites. × 2. The pellets of the damp-wood termites, *a*, are much larger than the more regularly formed ones of the dry-wood termites, *b*. From *Calif. Agr. Exp. Stn. Circ. 318, fig. 27.*

In wooden structures *Kalotermes minor* attacks only sound wood and is especially common in sapwood. It is therefore particularly abundant in untreated poles (figs. 74*a*, 79), but occurs also in posts, bridge piles, and occasionally in marine piling. In the sporadic cases of attack on buildings (pp. 247–255) it is most commonly found in window frames, door and window jambs, door sills, and in rafters and sheathing.

Nature and appearance of colonies.—The best indication of the presence of a wood-dwelling termite is its distinctive pellets. Those of *Kalotermes minor* (fig. 68*b*) are well formed and much smaller than those of *Zootermopsis* (fig. 68*a*). They will be found in great quantities within the galleries. Several pounds of them have been collected from a single heavily infested pole. In the more southern portion of its range, the pellets of *K. minor* are often thrown out from the workings, particularly when the colony is in suspended timbers such as rafters, and will be found on the floor below, indicating the location of the colony. In an apartment house in San Diego, California, whose studding and sheathing were infested, the ejected pellets formed conspicuous heaps around the bottom of the studding in the basement.

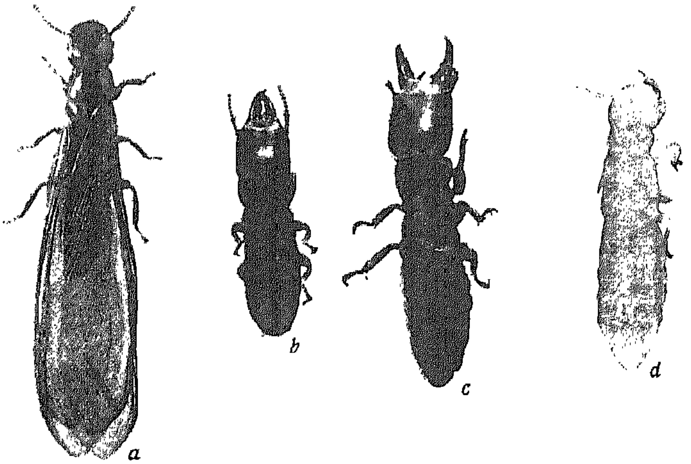


Fig. 69. The different castes of the common dry-wood termite, *Kalotermes minor.* × 5. *a.* Winged reproductive, or alate. *b, c.* Soldiers. *d.* Nymph, or immature stage. From *Calif. Agr. Exp. Stn. Circ. 318, fig. 18.*

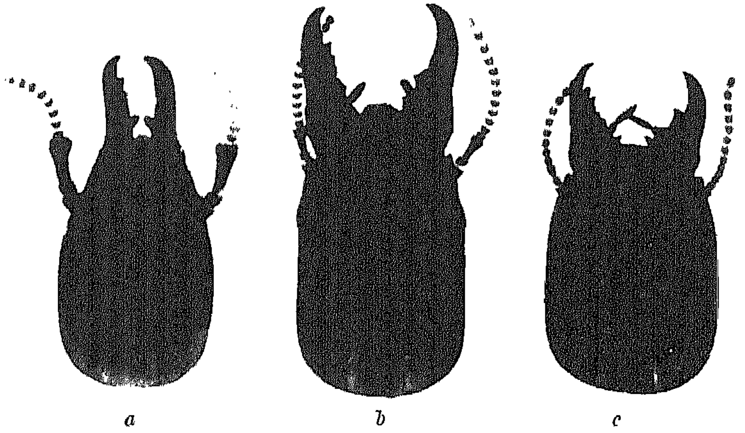


Fig. 70. The two western dry-wood termites and the desert damp-wood termite are readily distinguished by characters of the soldiers. The soldier of the southern dry-wood termite, *Kalotermes hubbardi, a,* has an enormous third segment in the antenna, nearly as long as the remainder of the antenna. The same segment in the soldier of the common dry-wood termite, *Kalotermes minor, b,* although considerably enlarged, is not longer than the next four segments together. The third segment of the antenna of the desert damp-wood termite, *Paraneotermes simplicicornis, c,* is but little, if any, enlarged. All × 20. From *Calif. Agr. Exp. Stn. Circ. 318, fig. 17.*

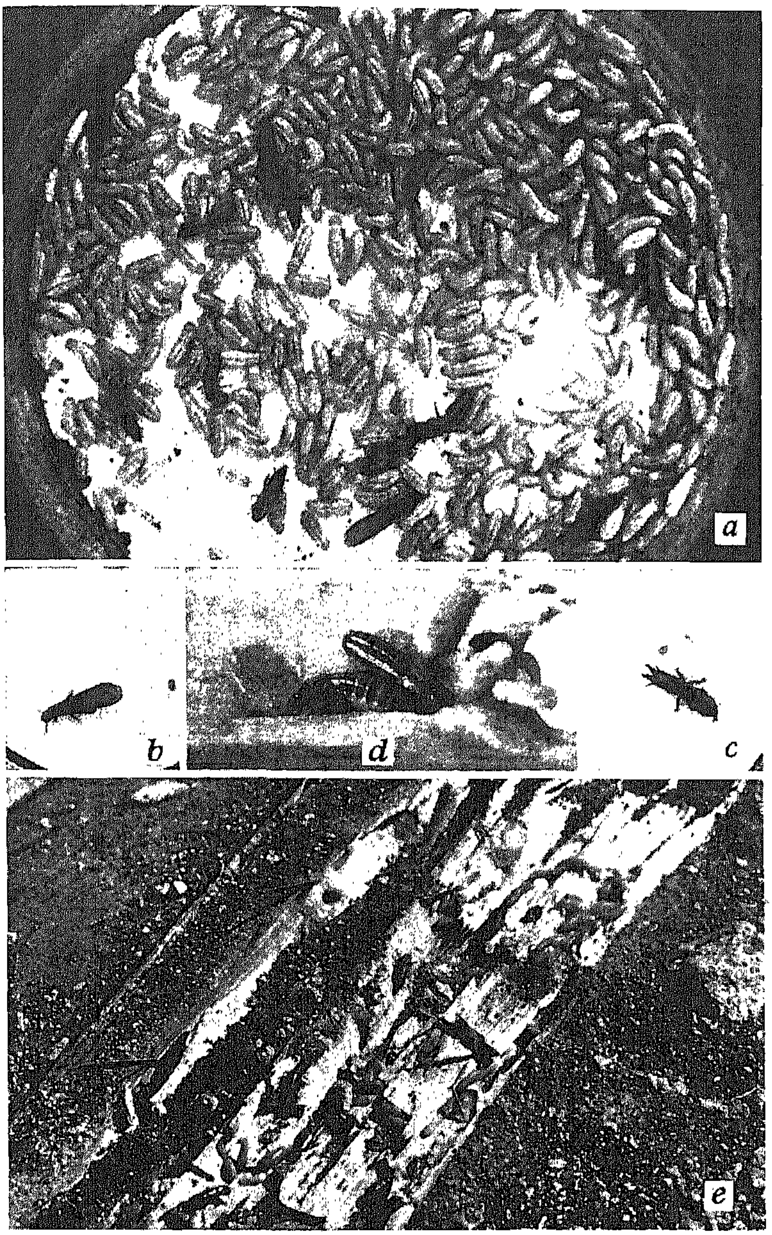


Fig. 71. Dry-wood termites, *Kalotermes minor*, as seen in life. *a*. Part of a colony, natural size, showing a few dark, winged alates, a few dark soldiers with larger heads and mandibles, and numerous whitish nymphs. *b*. Life size view of an individual alate. *c*. The same, of a soldier. *d*. A few nymphs and a royal pair (king and queen). × 2. The queen has the more swollen abdomen. *e*. *Kalotermes minor* in a ⅜ inch × 1½ inch wood lath which lay directly on roofing felt. A tunnel was made from the lath through the roofing felt into the wood sheathing. × ⅔.

The colony consists largely of the whitish nymphs in various stages (figs. 69*d*, 71), some of which in a mature colony bear developing wings, known as wing pads. Less common, although much more conspicuous, are the soldiers (figs. 69*b*–*c*; 71), with their reddish-brown heads, black mandibles, and brown bodies shading behind to dirty yellow. Persistent search may bring to light the dark-bodied king and queen (fig. 71*d*). The queen may show a certain degree of enlargement of the abdomen, but nothing to compare with that characteristic of ground-dwelling termites (fig. 1*h*). From early summer to mid-autumn the colony includes numerous winged individuals (figs. 69*a*; 71*a*–*b*; 72*b*–*c*). Immediately after molting these are white or imperfectly pigmented, but they later darken to lustrous reddish-black. These are the males and females, whose swarming is discussed below. The actual size of the individuals found in such a colony is indicated in the photograph shown in figure 71*a*.

Identification and description.—*Kalotermes minor* is associated in various sections of its range with species of termites belonging to each of the other habit types found in the United States, namely, the damp-wood termites, the subterranean termites, and the desert termites. Since the dry-wood termites present an entirely different problem than do the termites of any of the other habit types, it is necessary to be able to recognize them. A knowledge of their habitats and habits is useful to this end. The fact that they are confined to wood and produce fecal pellets (fig. 68) helps to distinguish them from the subterranean and desert termites. From the damp-wood termites, which also live in wood and produce pellets, *K. minor* differs in that it lives in dry, sound wood and that its pellets (fig. 68) are much smaller.

A glance at the reproduction in figure 164, of photographs of groups of damp-wood, dry-wood, and subterranean termites in natural size will make it clear that the dry-wood termites, *K. minor* (fig. 132*b*) are intermediate in size between the larger damp-wood termites, *Zootermopsis,* and the smaller common subterranean termites, *Reticulitermes.* The desert subterranean termites, *Heterotermes* (chap. 17), and the desert termites, *Amitermes* (chap. 18), are of about the same size as the common subterranean termites, and hence are easily distinguished from *K. minor.* This leaves only the desert damp-wood termite, *Paraneotermes simplicicornis* (p. 283) to be distinguished from *K. minor.* Since *Paraneotermes* is of about the same size and appearance as the species of dry-wood termites, it will be considered together with them.

Two other dry-wood species, *K. marginipennis* (Latreille) (chap. 22) and *K. hubbardi* Banks (chap. 22) occur within the range of *K. minor,* as noted in the discussion of distribution. A key is given below to allow for the identification of alates, soldiers or nymphs of these three species of dry-wood termites and of the desert damp-wood termite.

KEY TO THE NYMPHS OF TERMITES RELATED TO OR ASSOCIATED WITH *KALOTERMES MINOR*

1. Pronotum narrower than head, but little turned down at sides; antero-lateral corners very shortly rounded, nearly square.................................*Paraneotermes simplicicornis*

1. Pronotum broader than head, turned down at sides; antero-lateral corners broadly rounded 2

2. Pronotum nearly half as long as wide; anterior margin broadly but angularly concave........*Kalotermes minor*
2. Pronotum considerably less than half as long as wide; anterior margin evenly concave 3
3. Pronotum very short; anterior margin deeply concave; sides receding strongly, usually interruptedly, from near antero-lateral corner........*Kalotermes marginipennis*
3. Pronotum intermediate in length, anterior margin shallowly concave; sides receding from middle........*Kalotermes hubbardi*

KEY TO THE ALATES OF TERMITES RELATED TO OR ASSOCIATED WITH *KALOTERMES MINOR*

1. Dark with dark wings........ 2
1. Light with pale wings........ 3
2. Median near the radius sector and heavier than cubitus; generally brown........*Paraneotermes simplicicornis*
2. Median midway between radius sector and cubitus, of same strength as cubitus; body nearly black, head red-brown........*Kalotermes minor*
3. Much larger, about 19 mm. long with wings; pronotum deeply concave in front........*Kalotermes marginipennis*
3. Smaller, about 12–13 mm. long with wings; pronotum shallowly concave in front........*Kalotermes hubbardi*

KEY TO THE SOLDIERS OF TERMITES RELATED TO OR ASSOCIATED WITH *KALOTERMES MINOR*

1. Third segment of antennae little if any enlarged (fig. 70*c*)........*Paraneotermes simplicicornis*
1. Third segment greatly enlarged, club-shaped (fig. 70*a–b*)........ 2
2. Third segment very greatly enlarged, nearly as long as all remaining segments together (fig. 70*a*)........*Kalotermes hubbardi*
2. Third segment about as long as next four segments together........ 3
3. Pronotum very deeply excavate in front; a prominent tubercle on antero-lateral corner of dorsal surface of head........*Kalotermes marginipennis*
3. Pronotum not deeply excavate; no tubercle........*Kalotermes minor*

II. Life History of *Kalotermes minor*

BY

P. A. HARVEY

Swarming.—The alate of the common dry-wood termite, *Kalotermes minor*, is now known to be characteristically a day-flier, as its dark color indicates. In southern California it flies in the middle of the day, although earlier observations, made chiefly in Arizona, indicated that it was a night-flier (Snyder, 1920). This local difference in habit is no doubt a special adaptation necessitated by the high temperature and the low humidity conditions which characterize the day in arid subtropical regions.

The scattered records of dates of swarming obtained previous to the work of the Termite Investigations Committee indicated that the swarming season of *Kalotermes minor* was from July to December. In southern California the season extends from the latter part of September to the first of November. Apparently mature alates are found in some colonies as early as July, although under ordinary conditions they do not fly until much later. In the laboratory they have emerged as early as May. Under normal seasonal conditions scattering flights begin, in the vicinity of Los Angeles, late in September, increasing somewhat in number until middle or late October, when the peak of the swarm occurs. Sporadic flights follow the peak of the swarm until the first of November.

The meteorological factors important in connection with swarming are temperature and solar illumination. Unless both of these factors are optimum few flights take place. Brilliant sunlight from a cloudless sky and temperature that ranges from 80° to 100°F. are the optimum. If brilliant illumination prevails but the temperature is below 80°, there will be practically no flights; likewise, if the temperature is optimum but the sky is clouded, there will be very few flights.

The significant facts concerning the swarming of a termite species of economic importance are (1) the date or dates of swarming, (2) the time of day of swarming, (3) the number of swarming alates, (4) the strength and duration of swarming flights, and (5) the factors determining direction and point of termination of flight.

Observations on the swarming of *Kalotermes minor* were confined largely to southern California, from Santa Barbara to San Diego, and especially to certain stations there, as Table 8 indicates. There seems little reason to doubt that much the same conditions hold in general throughout the greater portion of the range of this species. In the fall of 1928 field observations of swarming did not begin until late October. Flights were observed on November 1, 16, and 19 in Alhambra, and on November 21 at Long Beach, California. Judging from observations made during the swarming seasons of 1929 and 1930, it is evident that these were late flights of alates which had developed slowly and swarmed after the peak of the annual swarm.

More definite data regarding the earliest and latest swarming dates were obtained during the fall of 1929 and 1930. In 1929 the first flights were observed at Long Beach on October 4, the last at Alhambra on October 25. In 1930 the first flight was observed at Alhambra on October 4, the last, also at Alhambra, on October 30.

Thus, judging from the observations made in 1929 and 1930, there is a period of about three weeks in October during which the main swarming of the common dry-wood termite ordinarily occurs. However, the peak of the swarming period, when the majority of the alates emerge, extends over a relatively short period. At Alhambra in 1929 it was on the 21st and 22nd of October. In 1930 it was on the 23d and 24th of October.

Granted that weather conditions are favorable the clock-like regularity of the appearance of the first fliers, the occurrence of the peak of the swarm, and the last straggling flights are truly remarkable.

From an economic standpoint the peak of the swarm is by far the most important. While no data are available regarding the number of alates which emerge from a given colony in advance of the main flight, field observations indicate that it is relatively small. Likewise, the number of fliers which emerge after the main flight from the colony is small, smaller indeed than the number of early fliers.

TABLE 8

SWARMING OF *Kalotermes minor* IN SOUTHERN CALIFORNIA

Location	Mature alates first observed	First flight observed	Peak of swarm	Last flight observed	Alates last observed
1929					
Alhambra	Sept. 10	Oct. 4	Oct. 21–22	Oct. 25	Oct. 25
Long Beach	—	—	Oct. 5–7	—	—
Santa Ana	Sept. 25	—	Oct. 8–10	—	—
San Diego	—	—	Oct. 6–21	Nov. 1	—
Santa Barbara	—	—	Oct. 29	—	—
1930					
Alhambra	July 21	Oct. 4	Oct. 23–24	Oct. 30	Nov. 11
Santa Ana	—	—	Oct. 15–17	—	—
Riverside	—	Sept. 26	Sept. 25–27	—	—
San Diego	Sept. 2	Sept. 25	Oct. 27–28	—	—
Santa Barbara	—	—	Oct. 4–6	—	—

While the last flights observed at Alhambra during the seasons of 1929 and 1930 were on October 25 and 30, respectively, alates were found in infested poles much later than this. When disturbed, they were unable to fly. The fate of such late alates is uncertain. In 1930 alates were found in poles at Alhambra on November 6, 7, 8, and 11. An unusual case was the occurrence of alates in a pole on January 28, 1931. Apparently, they were holdovers from the 1930 swarm, but the occurrence may not be significant, because the wood in which they were found had been in darkness from November 8, 1930, to the day on which it was opened.

The environmental conditions which accompany the peak of the swarm of the common dry-wood termite are a sudden rise in the temperature to a comparatively high point, and brilliant sunlight. The maximum temperatures and the nature of the solar illumination during the peak of the swarm for the seasons of 1929 and 1930 at Alhambra are given in Tables 9 and 10. Rain is apparently unnecessary to stimulate a general flight of the common dry-wood termite.

TABLE 9

TEMPERATURE, ILLUMINATION, AND NATURE OF SWARMING DURING SEASON OF 1929 AT ALHAMBRA

Date	Maximum temperature	Illumination	Swarming
October 3	92° F.	Brilliant	Scattered
4	95	Brilliant	Scattered
5	94	Brilliant	Scattered
6	93	Brilliant	Scattered
7	88	Brilliant	Scattered
8	81	Brilliant	Scattered
9	76	Partly cloudy	Very few
10	79	Brilliant	Scattered
11	88	Brilliant	Scattered
12	85	Brilliant	Scattered
13	84	Brilliant	Scattered
14	79	Partly cloudy	Very few
15	78	Partly cloudy	Very few
16	74	Cloudy	Very few
17	71	Cloudy	None
18	75	Cloudy	None
19	94	Brilliant	Scattered
20	99	Brilliant	Scattered
21	100	Brilliant	Peak of swarm
22	99	Brilliant	Peak of swarm
23	92	Brilliant	Scattered
24	85	Brilliant	Scattered
25	84	Brilliant	Last flight

While comparatively high temperature and brilliant sunlight are necessary to bring about swarming, some other factor or factors are evidently concerned since, although seemingly mature alates are present in the colonies in mid-July, flight does not occur until later, regardless of temperature and sunlight. As may be seen in Tables 9 and 10, the period from October 3 to October 8, during both 1929 and 1930, was characterized by maximum temperatures which ranged from 81° to 97° F., except on October 8, 1930. The illumination during this period in both seasons was brilliant, except on October 7 and 8, 1930. Yet, only scattered flights of the common dry-wood termite took place. However, only a few days later, during the period from October 21 to 24 in 1929 and 1930, the peak of the swarm occurred following a sudden rise in temperature. In both seasons the maximum temperature during this period of the peak swarm ranged from 85° to 100°F., except on October 21, 1930, when it was 76°. During the season of 1930 the peak of the swarm did not begin until October 23. An inspection of Tables 9 and 10 reveals the fact that each of the repeated swarms in the month of October in 1929 and 1930, whether scattered or at the peak, appears only when accompanied or preceded by a rise in temperature to 80° F. or above, and that the peak occurs during the maximum rise in both years. No rise above 80° occurs in October in either year without at least a scattered swarming. A correlation between swarming and a sudden change to a higher temperature is suggested by these facts.

TABLE 10

TEMPERATURE, ILLUMINATION, AND NATURE OF SWARMING DURING SEASON OF 1930 AT ALHAMBRA

Date	Maximum temperature	Illumination	Swarming
October 3	88° F.	Brilliant	None
4	93	Brilliant	Scattered
5	96	Brilliant	Scattered
6	97	Brilliant	Scattered
7	83	Cloudy	None
8	70	Cloudy	None
9	67	Partly cloudy	None
10	70	Partly cloudy	None
11	73	Brilliant	None
12	79	Brilliant	None
13	85	Brilliant	Scattered
14	76	Brilliant	Scattered
15	71	Brilliant	Very few
16	78	Brilliant	Very few
17	89	Brilliant	Scattered
18	84	Brilliant	Scattered
19	76	Brilliant	Scattered
20	71	Partly cloudy	None
21	76	Partly cloudy	None
22	88	Brilliant	Scattered
23	93	Brilliant	Peak of swarm
24	85	Brilliant	Peak of swarm
25	74	Brilliant	Scattered
26	79	Brilliant	Last flight

While in the swarming of subterranean termites moisture is the other limiting factor, it seems doubtful that there is any correlation between rains and the swarming of *Kalotermes minor.* The total precipitation at Los Angeles during September and October for the years 1928, 1929, 1930, and 1931 was 0.29, 0.32, 0.11, and 0.30 inch, respectively. In 1929 the 0.32 inch of rain came on September 17 and 18, while the peak flights were on October 21 and 22, more than a month later, with no intervening precipitation except a trace on October 1 and 2. In 1930 the peak flight came at approximately the same time, October 23 and 24, three weeks after the insignificant rain of 0.10 inch on October 3.

Emergence.—Data on the emergence of swarming alates were obtained from infested poles in the yard and in the field, from infested pole tops used in experiments on the infestation of poles (p. 230), and from an experimental building (p. 234).

Let us follow the course of events in an infested pole top. The alates are mature, the temperature is 95°F., it is midday, with brilliant sunlight. When a chip is removed from the outer shell of the pole, exposing the termites, their activity is not unlike that in a hive of bees. This is in marked contrast to the actions of the individuals in the colony at other periods of the year, when they are consistently quiet and plodding. Now, however, the nymphs are highly excited. They run about almost hysterically, with antennae nervously flashing back and forth. The soldiers are as much wrought up as are the nymphs; in fact, they have more the appearance of doing something than at any other time of the year. With legs wide apart and claws firmly attached to the spongy wood of the exposed passageway, they flash their antennae back and forth, and are apparently ready to attack anything that may come near. Agitation appears to be most acute near an emergence hole, an opening about 1/16 inch in diameter in the shell of infested wood near the top of the experimental pole (fig. 72*a*). Apparently, the nymphs made this opening to be used as an exit by the alates, because if a chip of wood is removed near a hole of this nature a group of much disturbed nymphs and soldiers will be exposed and some of the alates that appear to be grouped near the opening escape (fig. 72*b–c*). In fact, the impression is gained that the nymphs and, in particular, the soldiers are covering and protecting, if not actually assisting, the emergence of the alates. The soldiers appear to regulate the exit of the alates, determining the number that emerge at any one time, the recurrent cyclic emergence of groups of alates, and the time of emergence during the day. It should be stated, however, that recent evidence indicates that the alates themselves aid in digging an aperture for swarming.

The alates emerge in groups of from seven to twelve during the peak of the swarm, one individual following immediately after the other as if they were arranged in file just within the emergence hole, from which they issue as upon a prearranged signal. After one group of alates has emerged, there is ordinarily a pause of two or three minutes, presumably to allow another group of alates to gather near the emergence hole. Then the second group of alates emerges.

A number of such groups of alates, perhaps ten or twelve, emerge in this manner and then no more appear for from twenty minutes to half an hour, when the cyclic emergence of groups of alates is again repeated. Observations made during the swarming seasons of 1928, 1929, and 1930 indicate that the emergence of alates occurs from 11:30 A. M. to 3:00 P. M. during the peak of the swarming season, but that it is most common and rapid between 12:30 and 1:30 P. M.

Swarming flight.—The flight of the alate is aimless and more or less wavering. The insect usually rises at an angle of about 60 degrees, attaining an altitude of 30 feet in about 4 seconds, of 45 feet in about 8 seconds, and a maximum of from 60 to 75 feet in from 12 to 15 seconds. During ascension it travels 200 to 250 feet from the point of emergence. Having attained height, it flies rapidly in a definite direction and does not alight until it is a considerable distance from the starting point. Indeed, it has every appearance of being able to fly from half a mile to a mile or more, although it has been impossible to follow individual flights for more than 125 yards, because of the rapidity of flight, the elevation reached, and the brilliant sunlight.

Repeated observations show that the alate of the common dry-wood termite is as likely to fly away from the sun as toward it, and against the wind as with it. As the members of a group of alates emerge they do not follow each other in flight, but each takes its own course regardless of the others.

Table 11 gives information as to the direction of flight, rate of elevation, and speed of flight for eleven individuals carefully observed. Numbers 1 to 4 were observed at Alhambra on November 1, 1928, from 12:00 noon to 12:30 P. M., no wind; Nos. 5 to 9 were observed at Long Beach at noon on October 4, 1929, with a steady but moderate southwest wind; Nos. 10 and 11 were observed at Alhambra on October 30, 1930, at 2:00 P. M., with a west wind. In all three instances illumination was brilliant, with a cloudless sky. When last seen, the insects were flying strongly and were lost in the brilliant sunlight.

TABLE 11

DIRECTION, ELEVATION, AND DISTANCE OF INDIVIDUAL FLIGHTS OF *Kalotermes minor*

Individual	Elevation in seconds					Distance in seconds					Direction of flight
	4	5	10	12	15	4	5	10	12	15	
	feet	*feet*	*feet*	*feet*	*feet*	*feet*	*feet*	*feet*	*feet*	*feet*	
1	10-11	......	15-16	......	......	30-40	......	100	140	......	E-SE
2	40-60	......	100	......	......	80-100	......	120	......	......	S-SE
3	20-30	......	60-70	......	......	40-50	......	90-100	......	......	S-SE
4	40-50	......	......	100	......	40-50	......	......	300	......	S
5	30-35	......	......	60	......	30-35	......	......	300	......	N
6	30-35	......	......	45	......	30-35	......	......	300	......	NE
7	20-25	......	......	60	......	30-35	......	......	70-75	......	N
8	......	......	......	20-25	......	......	......	......	450	......	S
9*	......	......	......	......	......	......	......	......	......	......	......
10	8	12	35	......	45	15	35	60	......	75	NW
11	......	......	......	45	......	......	......	......	120	......	SE

* Weak flier, which made four or five attempts to fly, averaging from 6 to 10 feet.

In every flight there are a few fliers which are incapable of flying farther than 6 to 10 feet at a time, although four, five, or as many as seven such short flights are made by such an individual. It is possible that the weak fliers are less mature individuals. Such alates may, however, drop their wings, mate, and infest wood close to the colony from which they came. Successive short flights of weak fliers indicate that the typical alate may alight and then resume flight, but no actual field observations in this connection have been possible.

In addition to the typical fliers and the weak fliers there is a group of alates, of which every colony probably has a small number, which do not fly farther than 75 to 120 feet. Individuals in this group make one flight from the colony of about this distance, contact wood, and probably mate where they first alight. Individual flights of this nature have been observed in the field.

The number of alates produced by a colony is dependent on several factors, particularly the age of the colony and the fecundity of the queen. Some idea of the number of alates that emerge from an active, prolific colony during one swarming season was obtained from the results of three pole dissections made during the fall of 1930. Each pole was sawn into 2-foot lengths, and each section was splintered on a canvas to secure all of the alates. There was but one colony in two of the poles. As the alates were caught they were placed in alcohol. One pole, 40 feet in length, dissected at Riverside, California, September 26, 1930, contained 593 alates; the second pole, also 40 feet in length, dissected at San Diego September 19, 1930, contained 403 alates; another pole dissected at Los Angeles September 4, 1930, for which the number of colonies was not determined, contained 2,384 alates. When one considers the distance of flight and the fact that each alate is a potential member of a pair which may infest a building or a pole, the significance of a single mature, prolific colony of the common dry-wood termite becomes apparent.

Loss of wings.—Almost immediately after the alate has alighted it sets about actively to rid itself of its wings. Quickly spreading and lowering the wings until their tips touch the wood, it pivots first one way and then another, thus bringing pressure to bear on the wings at the basal sutures so that they break off. Occasionally the alate ceases these attempts to drop its wings and rushes away, dragging along one or more partially separated wings, to be lost later.

Pairing.—Divested of its wings, the reproductive, now often termed a *dealate,* mates, and is ultimately to be known as the king, if male, or the queen, if female, of a new colony. The high excitability and nervous activity which mark swarming and which are continued during the detachment of the wings now reach a climax. The wingless reproductive runs rapidly hither and thither until an individual of the opposite sex is encountered, whereupon both stop abruptly and stand with heads very close together, moving their antennae back and forth continuously over one another's heads. The king makes advances toward the queen, the queen striking at the king with her head. After four or five such overtures, each of which is followed by a pause during which the termites stand facing each other with their antennae fanning slowly, the king is accepted or rejected. If he is rejected the queen turns and runs quickly away and the king goes in the opposite direction. If, however, the king is accepted, the queen turns quickly and speeds away, with the king in close pursuit (fig. 72*d*). Although the queen runs rapidly, the king keeps close to her and, when they become separated as occasionally happens, the king rapidly regains contact with her (fig. 72*e*).

After pairing has been accomplished, separation seldom occurs. It is usually difficult to frighten members of a pair away from each other, and it appears that they seldom, if ever, leave one another for other mates, even though a number of unpaired termites are near. Instances have been observed of interference by an unmated king with a newly mated pair, but the union did not appear to be seriously threatened (fig. 72*f*).

Entrance into wood.—After pairing, a new cycle of events is initiated, involving a complete reversal of behavior. During the swarming period and while seeking a mate, the king and queen are attracted by the light, but after pairing they are repelled by it. The negative reaction to light is supplemented by a rapidly accelerated response to the feel of wood, and perhaps to its odor.

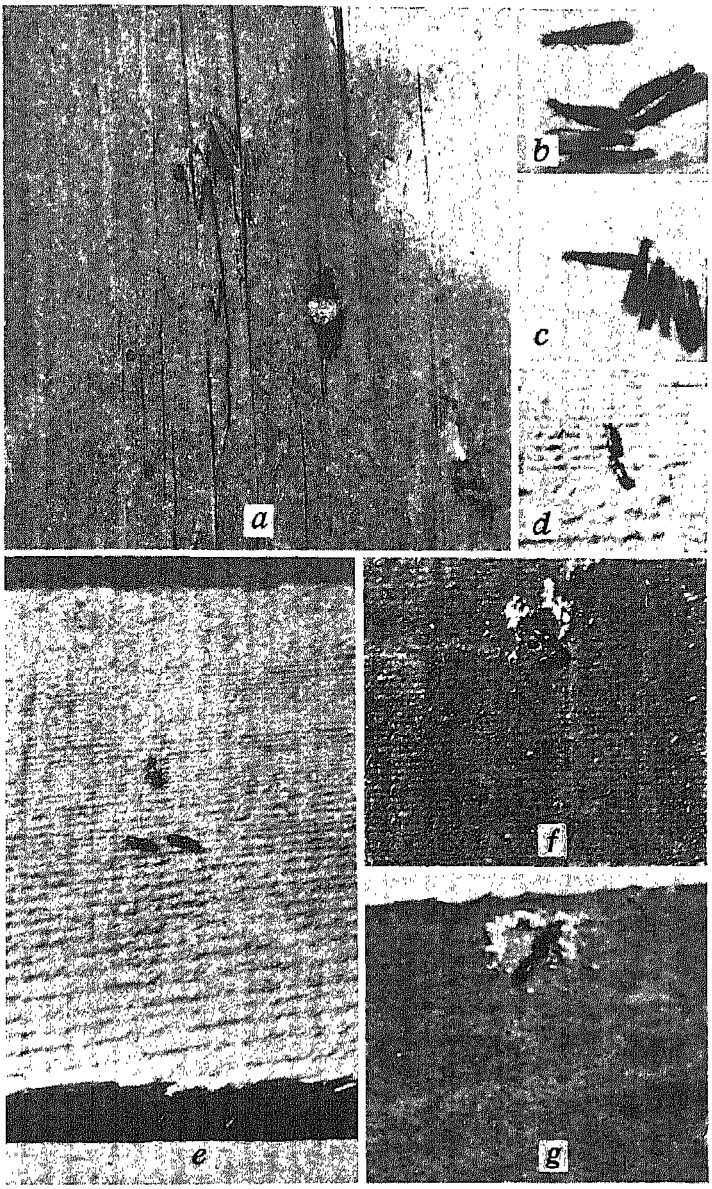


Fig. 72. *Kalotermes minor*. Photographs of emergence holes, alates ready to fly, and dealates, during pairing and infestation. *d–f*. Somewhat reduced, others about natural size. *a*. Surface of an infested pole, showing two sealed exit holes. *b–c*. Groups of alates ready for flight. *d*. Newly mated pair, male following female in search of entrance location. *e*. Reunion of recently mated king and queen, after their separation while in search of an entrance. *f*. Small piece of board showing a pair whose excavation is so deep as to hide all but the tip of the excavating individual. Excavated wood is piled near the aperture. The other member of the pair is repelling an unmated individual. *g*. Both members of a pair at work on the excavation.

The sequel is infestation of some dead portion of the tree, or some piece of wood of the building or pole on which the termites have paired.

The pair select a place to enter the wood and, working together, make a hole only large enough to admit one of them at a time. When the entrance becomes too deep for them to work together they alternate at the excavation, piling the particles about them (fig. 72*g*). When entry is completed they seal themselves in (*A* in fig. 34*b*).

The seal made at the entrance by a colonizing pair of common dry-wood termites when they enter wood is usually a plug of hard, brownish material which darkens later. This plug is a mixture of partially chewed wood and a secretion of the termites which acts as a cement. When it sets it is somewhat like hardened putty, and fills the entrance to a depth of between 1/16 and 1/8 inch.

The royal cell.—The entrance is usually about 3/8 inch deep. In making it the termites avoid summer wood, following the spring wood, even where this involves a sloping entrance. After sealing themselves in, barely sufficient room remains in the entrance for the royal pair, and almost immediately they begin enlarging it in the plane of the spring wood, adding to the seal with the excavated wood. Enlargement of the passage continues until a cavity has been made in which the pair can turn about. When finished it is somewhat flattened and broadly pear-shaped, with a short neck containing the plug (fig. 73*a*). In this royal cell the queen later lays the first eggs and here the colony takes its start.

The young colony.—The tremendous fund of energy that was in evidence during swarming, dropping of wings, and mating now abates and reaches a low level following excavation of the royal cell, and there follows a period of inactivity.

In nature this period of inactivity often lasts nine months, and many pairs do not survive it. The surviving pairs enlarge the royal cells, and egg laying begins. The young nymphs which hatch from the first eggs, from two to five in number, soon begin enlargement of the burrow, so that the amount of wood removed at the end of fifteen months is from 0.5 to 2.5 cc. (fig. 73*c*).

In most cases no order is apparent in the arrangement of the passages excavated from the royal cell by the young nymphs (fig. 73*c*). In some young colonies, however, there does seem to be a definite plan. In these instances a single large passage is excavated by the first nymphs which are produced, with its axis parallel to the vertical axis of the tree or pole. Occasionally, exploratory passages beginning with bud-like lateral openings are made at right angles to the main passage (fig. 34*b*). If, during the course of excavating the main passage, a check is encountered, the direction is altered and new side passages are begun.

As the first nymphs develop and continue to excavate, the queen lays more eggs in the advanced part of the main passage, and the young nymphs which hatch from these eggs carry on excavation of the wood along with the older nymphs. The king and queen remain in the advanced part of the main passage, where the nymphs make enlarged feeding chambers and new side passages. Penetration of the main passage into the wood is continued parallel to the main axis of the tree or pole. This passage is almost cylindrical, with slight, irregular flattenings at right angles to the radius of the tree or pole.

Toward the end of the second year after the colonizing pair enter the wood the young colony has destroyed about 3 cc. of wood and is securely established. At this time the colony consists of primary king and queen, one soldier, and a dozen or more nymphs.

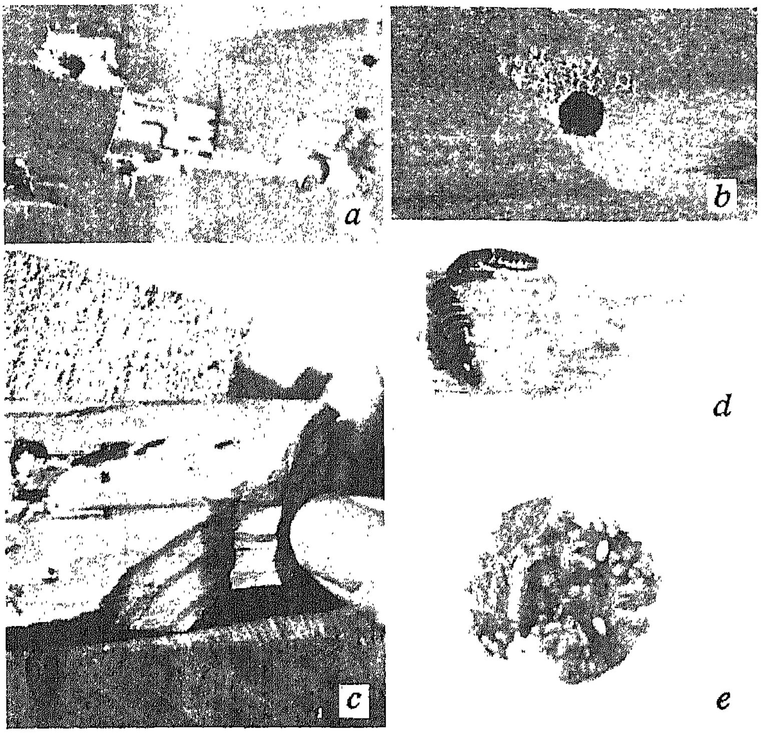


Fig. 73. Photographs of a pair of primary reproductives of *Kalotermes minor*, and the work of newly established pairs. *a*. Three recently excavated royal cells cut open, the two lower showing outlines of the cells. At right are two (dark) entrance holes. About one-half natural size. *b*. An entrance hole not yet sealed. × 3. *c*. Excavations made by a young colony about 15 months old, consisting of the royal pair and three young nymphs. Natural size. *d*. Royal pair of *Kalotermes minor* from a young, active colony. × 2. The enlargement of the queen's abdomen is noticeable. *e*. Seal made by *Kalotermes minor* over the mouth of a 5/16 inch vial. × 3.

Changes in the Primary Reproductive Pair

In the course of two years following the establishment of a primary king and queen in wood, some noticeable changes have taken place in the pair. In both there is a perceptible deepening of the color, which generally becomes a dark, reddish-brown. There is also a noticeable change in size in the queen. Her abdomen is greater in girth and is longer (fig. 73*d*). The king, on the other hand, usually does not increase in size, and sometimes appears to have become shortened if not actually shrunken. Measurements of ten primary queens that were known to be two years old indicate that the average increase in length of the primary queen of the common dry-wood termite during the first two years is about 0.8 mm.

SUBCOLONIES AND SUPPLEMENTARY REPRODUCTIVES

Supplementary reproductives of *Kalotermes minor* are occasionally encountered in mature colonies in the field. They have also been produced experimentally in the laboratory in isolated groups of nymphs. Information on the development of such young subcolonies has been secured from laboratory experiments in which groups of twenty to thirty older nymphs were isolated in wooden cells. The nymphs thus isolated ordinarily succeed in establishing themselves in the wood, and two of them develop into supplementary reproductives, king and queen. The other surviving nymphs are not modified, but, as in the parent colony, continue to aid the supplementary king and queen in excavation and in the care of the young colony resulting from the reproductive activities of the supplementary king and queen.

In the laboratory, supplementaries commonly develop from nymphs in the sixth instar and less commonly from those in the seventh and the fifth instars, but never, apparently, from nymphs in a lower instar. In groups containing two individuals each from the third, fourth, fifth, sixth, and seventh instars, the two individuals in the sixth instar become supplementaries. In groups containing only one individual in each of these instars, the sixth instar nymph becomes a supplementary reproductive. Whether the seventh instar nymph ever becomes a supplementary under these conditions has not been determined. In a group of eight nymphs of the sixth instar at least two, and sometimes three or four of the nymphs become supplementaries.

The first evidence of change in the individuals of the sixth instar that are becoming supplementaries appears within four days to one week after they have been isolated in the cell when kept at 80° F. and a relative humidity of 70 per cent. It consists of a definite deepening of the color tone of the entire body, head as well as thorax and abdomen. Those nymphs that are not becoming supplementaries retain their original white or light brown color without any suggestion of change. The onset of the color change varies in different individuals, as does its rate of progress. At the end of two weeks following isolation the change in the color of individuals that are becoming supplementaries is marked. The abdominal segments begin to be more clearly defined, and a median dorsal line in the abdominal region becomes noticeable. At the end of three weeks these individuals are a pronounced olive-green or bright amber in color over the entire dorsal surface, and the median dorsal line is prominent. This line is dark brown in color and extends from the mesothorax to the tip of the abdomen. In some individuals at this time, also, the eyes become conspicuously pigmented, almost black. At the end of a month these color changes reach a maximum.

The first egg is laid at about the end of the second month, and at the end of the first year following isolation of such a group of nymphs the progeny of the subcolony consists of from five to twelve nymphs in the first to the fifth instars, inclusive.

Supplementaries arising from nymphs in the seventh instar do not develop so rapidly as those from nymphs in the sixth instar, and do not show so marked a change in color. Definite changes in the external structure do, however, appear, the most marked of which is a sharpening of the abdominal segmentation due to increased chitinization. This begins in about three weeks following isolation, and is accompanied by an increase in the length of the abdomen, and a decrease in abdominal girth. Six weeks after isolation each abdominal segment of such individuals stands out plainly. Each tergite is arched, and the intersegmental regions deeply cleft. The elongation and decrease in the girth of the abdomen have continued, so that in general appearance, although not of course in size and color, the supplementary resembles a primary queen of the western subterranean termite. After about six weeks of isolation the girth of the thorax has also decreased, this change usually paralleling the changes in the abdominal region. This gives the thoracic region a somewhat pinched appearance. It appears also to be more heavily chitinized than in the nymph. It is in the thoracic region that the only marked change in color appears. It becomes light, bright amber.

Supplementaries from nymphs of the seventh instar seem to reach maturity in about three months following isolation. A few eggs laid by these reproductives have been secured, but no information has been obtained as yet regarding egg laying and development of the subcolony with seventh instar supplementary reproductives.

THE MATURE COLONY

The development of the colony has been followed for only two years. The only available information, therefore, in connection with the mature colony is based on field observations supplemented by field and laboratory experiments. These observations indicate that the mature colony is a complex community consisting of a primary king and queen, many nymphs, and a number of soldiers, and occasionally one or more secondary queens. The nymphs range from the very tiny newly hatched individuals in the first instar to larger individuals with wing pads in the seventh instar. From early in July to the close of the swarming season in late October alates are also present in the colony. For numbers of individuals in the different castes in natural colonies see pages 240–246. Supplementary reproductives are not usually found in the mature colony, and probably are not produced unless the primary and secondary queens are destroyed.

As has been brought out above, the young primary queen lays the first eggs in the enlarged royal cell. The queen appears to keep in the van of the activities of the young colony, depositing eggs at the end of the main passage and in the side passages, where the now growing nymphs are at work. When the eggs hatch the young nymphs are in galleries with the older nymphs and

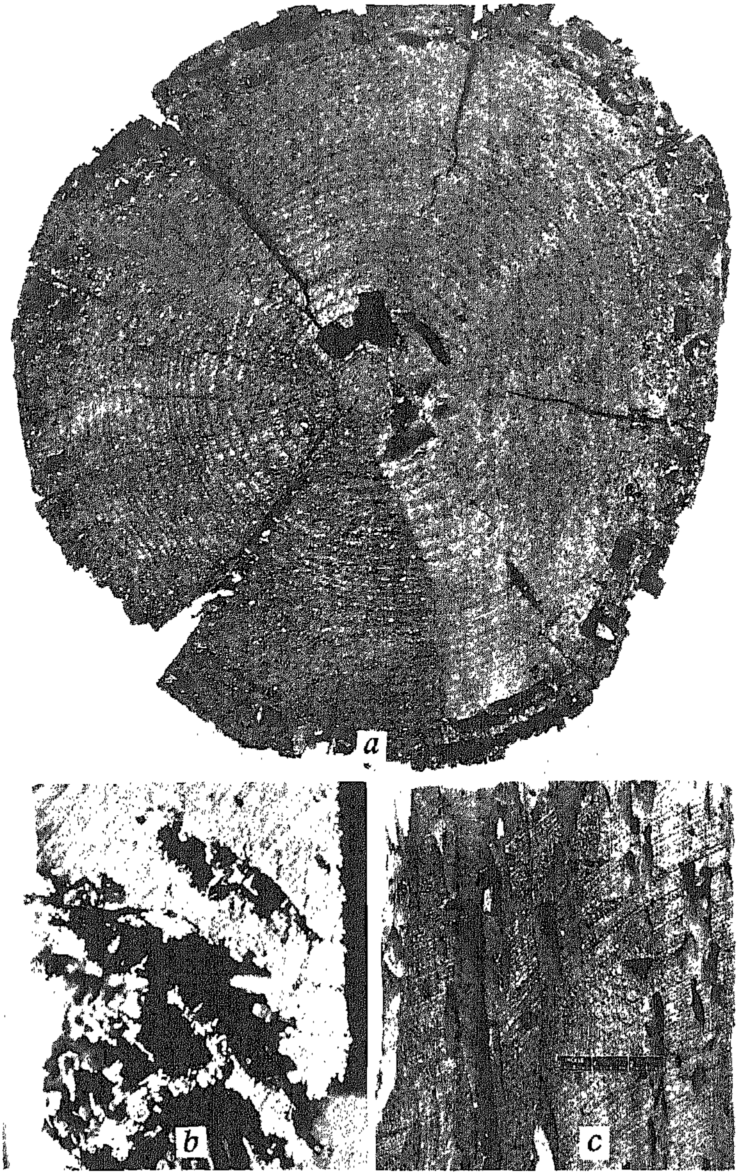


Fig. 74. Workings of the common dry-wood termite, *Kalotermes minor*. *a*. Cross section of a cedar pole showing characteristic location of workings. Sapwood is preferred, but galleries are usually present in the center of the heart, probably as a means of escaping extremes of temperature. *b*. An extreme case of destruction of wood in a crossarm. *c*. Workings in a square pole. The galleries are by no means confined to single annual rings, and in soft wood are made quite independently of them.

therefore may be taken care of by the older members of the colony. The young nymphs soon join the older nymphs in enlarging and extending the existing passages, resulting in an extensive series of intercommunicating galleries and chambers.

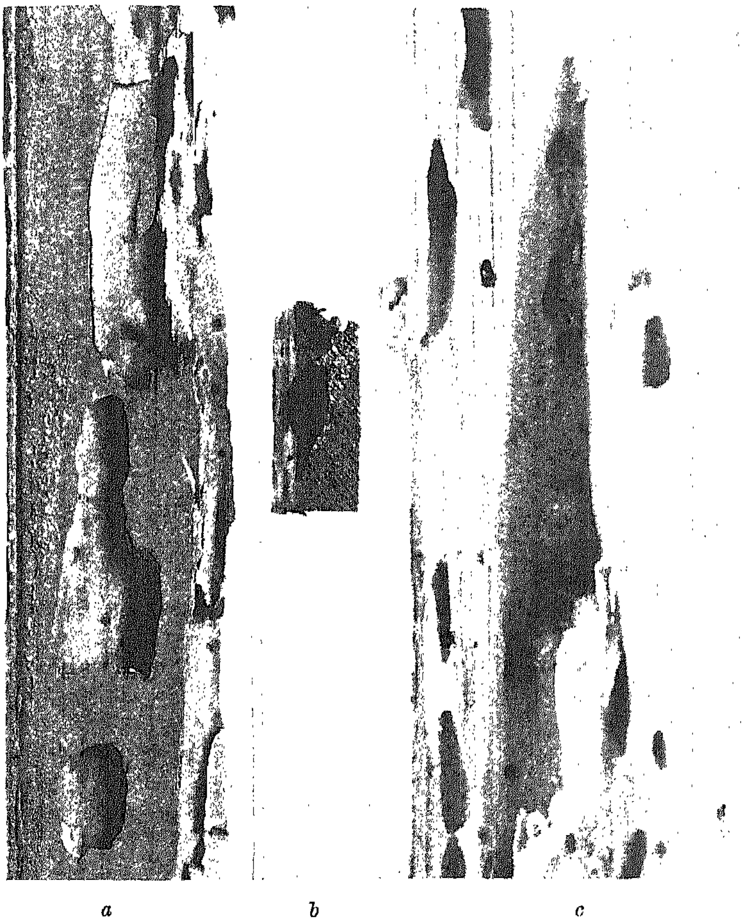


Fig. 75. Workings of *Kalotermes minor* in house timbers. They often approach the surface, leaving a paper-thin outer layer (*a* and *b*), and are easily located by pressure.

When the galleries of a mature colony are opened, pellets, eggs, nymphs in every one of the seven instars, a few soldiers, and perhaps the primary pair, will be found in the galleries where the activity of the colony is greatest (fig. 71*a*, *e*). In the passages that are in the rear of the center of activity numerous older nymphs are actively enlarging the galleries, and still farther in the rear are galleries where few if any nymphs are present. Here the wood has been so completely riddled that the termites can no longer work without destroying the outer protective shell (figs. 74*b*, 75).

The egg-laying period of an active, prolific queen begins in late spring and ends in late fall. However, even the most prolific queen does not lay continuously throughout this length of time. For a week or ten days she lays from one to twelve eggs each twenty-four hours, and then ceases egg laying for a month or more, after which she resumes it at the same rate as before.

The primary queen deposits her eggs among the pellets, which are heaped in the bottom of the gallery like grains of wheat in a bin. The incubation period in one- and two-year-old colonies is seventy-seven days when the temperature is kept at 80° F., and the relative humidity at 83 per cent. After hatching, the nymphs, which are delicate, wander uncertainly about among the pellets.

During the second year of her existence the primary queen of a young colony usually produces about eight eggs, with a maximum of twelve or fifteen eggs. Her fecundity increases, however, with each succeeding year, and probably reaches a maximum when she is from ten to twelve years old. It drops then, perhaps rapidly, with secondary queens appearing in the colony to assume the functions of the primary queen. Whether or not all of the secondary queens that develop become active in continuing the colony has not been determined.

The progeny of a primary queen, produced intermittently during the period from spring until fall, represents the annual increment for that particular colony. Few, if any, eggs are laid during the winter, which is a period of relative inactivity not only for the queen but for the other members of the colony as well, at least under conditions in California.

Probably more than a year is required for a nymph to develop from the egg to an alate or a soldier. Under natural conditions it passes, during this time, through seven instars. The duration of each instar at 80° F. and 83 per cent relative humidity, with the average length of the individuals in each, is given in Table 12.

TABLE 12

DURATIONS OF NYMPHAL INSTARS OF *Kalotermes minor*

Instar	Average length of nymphs, in mm.	Number of individuals observed	Duration of instar, in days
First	1.59	12	21–35
Second	2.39	5	30–42
Third	3.18	6	24–47
Fourth	4.77	2	56–56
Fifth	6.36	6	28–75
Sixth	9.54	14	17–80
Seventh	9.54	10	12–80
			188–415

These observations were made on isolated groups of several termites kept at 80° F. and 83 per cent relative humidity. The sums of the minimum and of the maximum durations of the seven instars are 188 and 415 days, respectively, suggesting a wide latitude in the duration of the nymphal period. The termites are social insects, among which the life of the individual is prolonged and does not depend on an annual cycle of food, because of a continuously available supply of wood and fungi. There is therefore possible a wide variation in the length of time that is spent by different individuals in the several instars. This variation, together with the varying lengths of time that the newly formed alates remain in the colony before swarming, makes possible a definite seasonal swarming period and the swarming of different colonies at different times, and in different years at different times.

The wide variations in the duration of the last three instars are correlated with the occurrence of from one to three additional, or "interpolated," molts in the fifth, sixth, and, occasionally, in the seventh instars. These molts, not previously reported, I term interpolated molts in contrast to the ecdyses which terminate the instars in question. These instars are separable by size and structural characteristics, which the interpolated molts do not noticeably modify.

Evidence based on field observations and field and laboratory experiments indicates that the population of a colony of the common dry-wood termite is distributed among the castes about as is indicated in Table 13, although the constitution of any given colony is probably largely dependent on environmental conditions.

TABLE 13

ESTIMATED NUMBERS OF INDIVIDUALS OF ALL KINDS IN COLONIES OF *Kalotermes minor*

Age of colony in years	Reproductives	Soldiers	Nymphs
1	Primaries	0	0
2	Primaries	1	12
3	Primaries	3	50
4	Primaries	10	200
5	Primaries	20	500
6	Primaries	30	700
7	Primaries	40	1,000
8	Primaries; one or more supplementary reproductives	50	1,200
9	Primaries; one or more supplementary reproductives	60	1,400
10	Primaries; one or more supplementary reproductives	70	1,600
11	Primaries; one or more supplementary reproductives	80	1,800
12	Primaries; one or more supplementary reproductives	90	2,000
13	Primaries; one or more supplementary reproductives	100	2,200
14	Primaries; one or more supplementary reproductives	100	2,400
15	Primaries; one or more supplementary reproductives	120	2,600

For counts of the populations of adult colonies see pages 240–246.

ACTIVITIES OF THE COLONY

The mature colony occupies the extensive intercommunicating excavations which successive annual increments of termites have made during their lifetime in the wood. It is only rarely that these galleries suggest any definite pattern; ordinarily they are a disorderly aggregation of irregularly cavernous passages that riddle the wood.

If the colony is in a dead tree or a pole, the passages are usually most numerous in the sapwood, which often becomes a mere shell or skeleton framework as a result of the destruction of the wood by the termites; however, a protective shell is always left surrounding the galleries. Thus the tree or the pole often has the appearance of being perfectly intact, although it is, in fact, permeated with passageways. However, checking and mechanical injuries to the pole often result in breaking the protective covering of wood, thus exposing the galleries. In many cases the extrusion of pellets from the passages of the termites reveals the infested condition of the pole.

In a badly infested tree or pole the passages will be found extending into the heartwood. They have the same disorderly arrangement as the passages in the sapwood, although sometimes the termites appear to have worked toward a particular area, which they tap with a connecting passage from the main part of the colony and proceed to burrow, disregarding temporarily the other parts of the tree or pole. Cavities of considerable size are often found in the heartwood near the tops of poles, which may serve as retreats from extremes of heat and cold.

The common dry-wood termite not only appears to utilize the sapwood of a tree or pole more than the heartwood, but works in it more rapidly. But in the sapwood, as well as in the heartwood, the dry-wood termites often work without apparent regard for the annual rings. They may riddle the summer wood as rapidly and as thoroughly as they riddle the spring wood. In this particular they differ from the subterranean termites, which select the spring wood where feasible.

CHAPTER 21

ECONOMIC SIGNIFICANCE OF THE COMMON DRY WOOD TERMITE

I. GENERAL ECONOMIC SIGNIFICANCE

BY

S. F. LIGHT

Kalotermes minor, the common dry-wood termite, has been the cause of extensive damage to poles in the areas infested (fig. 67). In much of this area its attacks are confined largely to the lower part of the pole. There seems reason to believe that much of this can be eliminated by butt-treatment of poles. In other parts of the area, notably in the coastal area of southern California, attacks on the tops of poles are common (fig. 80). If this is to be prevented full-length treatment will be necessary. The destruction of wood in poles by *K. minor* is usually confined largely to sapwood and hence, aside from failures due to damage to pole tops, is not as a rule of a nature to necessitate replacement for mechanical reasons. For further discussions of the relations of *K. minor* to poles see the chapters on "Power, Telephone, and Telegraph Lines" (chap. 49) and "Railroad Structures" (chap. 51), and pages 234–246.

The total cost of damage known to have been done by *Kalotermes minor* in houses is relatively small. Table 14 is extracted from figures furnished to the Termite Investigations Committee by the County Agricultural Commissioner of Los Angeles County for the period from September 1, 1929, to August 14, 1931, during which period termite control operators were licensed and required to report on all operations.

TABLE 14

	Number of jobs	Total cost	Average cost of repairs
Kalotermes minor	100	$ 6,507.06	$ 65.07
Reticulitermes hesperus	2,901	254,690.92	87.79
Kalotermes minor and *Reticulitermes hesperus*	220	26,237.44	119.26
Kalotermes and fungus	16	1,457.93	91.12
Reticulitermes and fungus	638	108,395.86	169.89
Kalotermes, *Reticulitermes*, and fungus	45	10,716.11	238.13
Other cases involving *Kalotermes*	17	……	……
Other cases involving *Reticulitermes*	94	……	……
Total cases involving *Kalotermes*	398	……	……
Total cases involving *Reticulitermes*	3,898	……	……

From this it will be seen that *Kalotermes* damage was reported in about one-tenth as many cases as was *Reticulitermes*, and that the average cost for 100 cases was about $65.00, as contrasted with an average cost of $87.79 for some 2,900 cases of *Reticulitermes*.

Three hundred cases treated by the G. Edward Chase Company of San Diego, California, in 1930 were reported as given in Table 15.

TABLE 15

Wood rot only	62 cases
Kalotermes only	29 cases
Reticulitermes only	89 cases
Wood rot and *Kalotermes*	4 cases
Wood rot and *Reticulitermes*	99 cases
Kalotermes and *Reticulitermes*	8 cases
Wood rot, *Kalotermes*, and *Reticulitermes*	9 cases

While the damage done by *Kalotermes* to buildings is not large, the economic problem presented is a difficult one, owing to the fact that the colonizing alates are able to enter wood at all levels (fig. 38), and the difficulty of preventing such entrance short of the use of resistant materials. Furthermore, in the most heavily infested areas reinfestation is possible, since colonies are to be found in trees, including palms. Most infestations in structures are above ground level and often in the upper parts of buildings, so that the total extent of damage by the dry-wood termites is difficult to determine and is probably underestimated.

A single typical case of damage to a building by dry-wood termites will be discussed and illustrated here. Details concerning a number of such cases will be found on pages 247–255. The case cited here was reported in "The Architect and Engineer" by Kofoid and Garland (1929). Quoting from their account:

> The structure attacked was a two-story brick building erected in 1888 (fig. 76). At one side of the building there had been an outside stairway on brick walls leading to the second floor, beneath which wood was stored. Later this was transformed into a flat-roofed storeroom with a skylight, but the door above was retained and the opening closed by a sliding fire door.
>
> The building was occupied by a furniture store. On the second floor was a thick wool carpet with a heavy felt mat beneath it. The floor was of Douglas fir, resting on the redwood false floor and this in turn on 2 inch × 16 inch Douglas fir joists 50 feet long, with bridging along the brick wall, and two 2 inch × 16 inch 8-foot scabs extending out from the brick wall along each joist. The fire door, the door jambs, and door sill were of redwood.
>
> The first indication of the presence of termites in this building was noticed about August 28 in the second floor near an outside door. Pellets were noticed underneath an antique birch cabinet. Each time the cabinet was moved to sweep the carpet there would be a new pile of pellets and upon close examination holes were seen through the wool carpet which covered the entire floor, and small holes penetrating the 1 x 4 tongued and grooved Douglas fir flooring were observed. There were four different locations where holes were observed through the carpet and felt floor covering. Upon removing the carpet and felt covering and the first floor, holes were observed penetrating the redwood subfloor. Upon removing the subfloor there were holes penetrating the 2 x 16 Douglas fir floor joists. A section of the

floor was then removed at either side of the outside door about 4 feet in width, and for half or about 25 feet of the width of the second floor, which floor was about 50 feet in width. The termites had attacked nine of the 2 x 16 scabs on either side of the floor joists for their full length of 8 feet. Also two of the main floor joists had been attacked for about 23 feet.

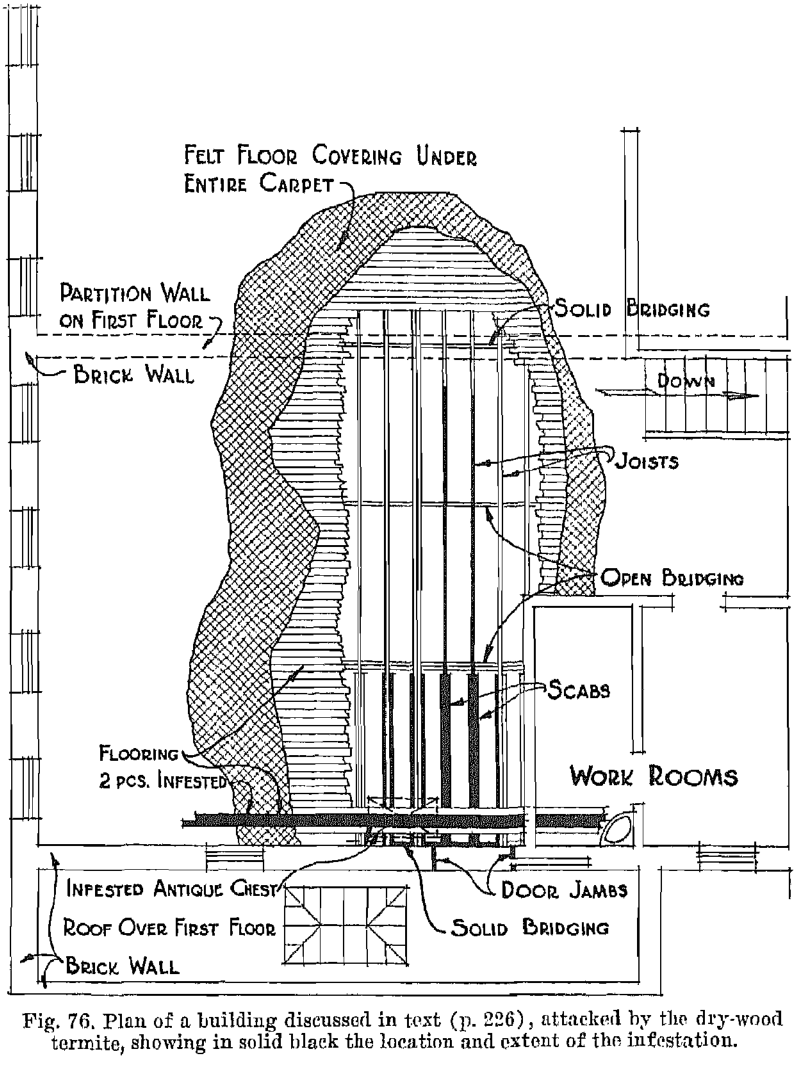


Fig. 76. Plan of a building discussed in text (p. 226), attacked by the dry-wood termite, showing in solid black the location and extent of the infestation.

Only two sections of the 1 x 4 Douglas fir flooring had been attacked, extending about 18 feet in one direction from the door and about 10 feet in the other direction. The termites had crossed one joint in the Douglas fir flooring, but no more.

The solid bridgings between the floor joists near the door were the most severely attacked, two of them having been damaged at least 50 per cent, the other damage being in no place in excess of 10 per cent. The redwood door jambs around and over the top of the outside door, as mentioned above, had been penetrated with one or two holes clear around the casing and the first 2 inches next to the floor of one side of the door jamb had been damaged to about 25 per cent. The bottom inch strip on the metal covered sliding fire door had been penetrated for its full width. This and the door jambs were the only two instances where redwood had been attacked.

Two of the front legs of the chest were resting directly over the two pieces of infested flooring. Each leg had a single hole penetrating into the bottom. One leg seemed to be more infested than the other and was removed from the chest, creosote poured into the hole, and in a few minutes was turned right side up and tapped with the result that approximately 500 termites came from within the leg. The other leg was apparently not badly attacked. The selection of two boards only out of the many available in the Douglas fir flooring and the passage from one to another across the end but not from side to side is also quite characteristic.

The selection of two joists only and of nine consecutive scabs and the omission of three of the joists included between them is a unique illustration of the preference of the termites for particular pieces of wood. It is quite probable that this run of adjacent scabs was cut from the same timber, or at least from the same log. They may well have been from the same one as that from which the two joists which were attacked were sawed. In any event our observations on attacks by termites upon wooden structures are quite generally characterized by the fact that, given the choice of timbers in the path of their ravages, they enter some timbers and leave others, even though in location, appearance, and kind of wood the timbers are similar. Factors, such as the hardness of the wood, the amount of its resin, its age in the tree, and its chemical content, enter into the determination of the selection by the termite.

Investigations made by Dr. Noyes in our laboratory at the University show that the jaw of the termite which gnaws the wood is one of the most intensively innervated structures of the body, and that sense organs end in nearly every hair on the antennae, legs, and mouth parts, and specialized groups of peculiar sense organs, some of which are probably olfactory, occur on the mouth parts and antennae. Termites are equipped to touch, smell, and taste; to sense the resistance of the wood they gnaw, and seemingly become aware of strain upon the wood itself.

The attack upon the antique chest presents an unusual situation in that the termites apparently detected it above the flooring, even though isolated from it by felt and carpet. An analysis of this attack reveals certain significant characteristics. Entrance of the colony was probably made around the door on the second floor, although it is probable that the single burrow carried entirely around the jambs in the redwood was concerned with an outlet for swarming. The attack upon the bottom strip of the fire door was possibly a blind alley explored on the way into the building. The heavy attack in the bridging against the brick wall is severe because it is the oldest region of invasion and also favorably located as to moisture.

In the attack within the building the avoidance of the redwood false floor, except for transit, is striking. Termites, especially the soldiers, have the habit of "shimmying" in their burrows and rattling their heads on the sides, apparently communicating alarms in this way. Possibly the density of the adjacent structure modifies the sound so as to guide the extension of the burrows, even across a barrier such as that of the felt and carpet.

One other suggestion might present itself, namely, that the termites were introduced in the chest and went down into the floor through the carpet in the first place. The short time the chest had been on the floor—about a year—does not suffice, however, to provide for the growth of the colony to the size detected on exploration. It is probable that at least several years were required for such long extensions of the colony into the joists and floor, as were found.

The colony was exterminated in part by the removal of the infested pieces and in part by the injection of creosote into the burrows through small auger holes at intervals into the timbers. [The poison dust method had not been developed at that time.] It appears from the selection made by *Kalotermes* that Douglas fir is more to its taste than redwood, that some Douglas fir timbers are more attractive than others, and that redwood will be traversed (jamb and false floor) to get to other timber, or will be taken (fire door) when other wood is not in contact with it.

Prevention of attacks such as this by the dry-wood termite on buildings such as this may be afforded by careful attention to certain details of construction. In the first place, there should be a perfect bond made between the mortar and the door jambs and window frames which should not be disturbed in the later finishing of the opening. In the second place, there should be close jointing of the wood members around all openings and a complete coverage of all joints and checks by putty and paint. Under these conditions of good construction the swarming king and queen will find it difficult to get a point of entrance into the wood used in the building.

The attack of *Kalotermes* on the bridging along the brick wall and into the ends of joists and scabs extending from this wall is an illustration of their sensitiveness to areas where there are slight differences in moisture. Laboratory tests of termites show that they are exceedingly sensitive to the slightest difference in moisture content of the air and will very quickly go to the region of greater moisture content. Brick walls, during the rainy season, accumulate a slight amount of moisture and retain it for some length of time. The ends of timbers in contact with this region are thus favorably located for termite attack.

Types of construction in which the ends of such timbers have ventilation provided by a small air chamber around their sides and at the rear of their ends are recommended in Appendix W-1 on Termite Protection in the Building Code of the National Lumber Manufacturers Association. This space provides for more circulation of air and dissipation of the moisture and thus reduces somewhat the attractiveness of this region to termites.

The fact that the area beneath the stairs had been at one time used for storage of wood for fuel suggests the possibility of the introduction of *Kalotermes* in oak wood, which sometimes happens, but such wood is usually cut up to such an extent that the ants quickly get access to the termites and eradicate them. The entrance of the king and queen in a crevice around the opening at the swarming season is much more probable than the migration of termites from stored wood into the door some feet above the wood. [The swarming alates may have come from colonies in the wood.]

Good construction can undoubtedly greatly reduce the incidence of termite attack upon buildings. Every center of infestation eliminated in a community reduces the probability of the spread of the infestation elsewhere.

II. Colonization of the Common Dry-Wood Termite in Wooden Structures

BY

P. A. HARVEY

Checks with a maximum gap of 1/8 inch and a maximum depth of about 1 inch appear to be most favored by colonizing pairs of *K. minor* in entering poles. Another natural path of infestation in poles by the common dry-wood termite is by way of knots, particularly if the knots are broken or cracked, although even then knots are less favored than checks. Incidental paths are mainly crevices about the crossarm, and it is because of them that the top of the pole is favored as a path of infestation. However, while the data that have been collected in connection with swarming indicate that the top of a pole is subjected to contact of more flying individuals than any other part, pole dissections show that separate colonies become established in the lower part of the pole about as frequently as in the top. Infestation in the crossarm or in the body of a pole near the top may result from entrance of reproductives about the gain through checks or cracks in the crossarm, as well as through checks or cracks in the pole top itself.

Spur marks afford another incidental path for infestation particularly favorable for low-flying individuals. These alight on the lower part of the pole, mate, and seek an entrance where spur marks are most abundant. One pole in San Diego, for example, in place less than a month, was found to have signs of entry in each spur mark within reach of the ground.

It would seem that the weathered surface of the top of a pole would be favorable as a path for entrance of reproductives, but neither in field observations nor in field experiments have such infestations been found to occur, except where advantage had been taken of a check that extended through the top. Observations and results of experiment indicate, also, that direct penetration of the surface of a pole or a board without the aid of a check or crevice or other opening occurs but rarely.

Experimental pole infestation.—Field experiments designed to secure information regarding the infestation of poles by reproductives of the common dry-wood termite were set up during the swarming seasons of 1929 and 1930. Those of 1929 were located at Alhambra and Los Angeles, and those of 1930 at Alhambra and San Diego. The results of these tests are found in Table 16.

In the Alhambra experiment of 1929 pole tops recently received from an area not infested with *Kalotermes,* each 6 feet high, with a short crossarm attached 8 inches from the upper end, were set 6 inches in the earth in each of two muslin-covered frameworks 25 feet x 6 feet x 6 feet. One such uninfested pole was set 2½ feet from each end of each of the two enclosures. In the center of each enclosure three pole tops containing alates of the common dry-wood termite were set in the earth at equal distances between the uninfested end poles. Emergence of the alates occurred from the 21st to the 23d of October. Although many of them escaped by crawling through the meshes of the muslin, numerous individuals mated within the enclosure and some of the newly mated pairs infested the new pole tops.

The Los Angeles experiment differed only in details. Here the enclosure was 46 feet x 6 feet x 6 feet. Six uninfested red cedar pole tops of the same size and with crossarms as in the previous experiment were set 6 feet apart in the enclosure. Two pole tops containing alates were also set in the enclosure. Emergence of the alates occurred October 8, and while many of them escaped or entered the framework, some of the newly mated pairs infested the new pole tops.

The set-up at San Diego in 1930 was in a similar enclosure. Twelve new pole tops of the type used in the previous experiments, together with three pole tops containing alates, were set in two rows. Emergence occurred October 27.

The fourth field experiment was at Alhambra and involved the use of fifty new pole tops of the type previously used, together with twelve tops containing alates, which were set about 3½ feet apart. Emergence of alates occurred October 23 and 24.

TABLE 16

PATHS OF ENTRANCE OF COLONIZING PAIRS IN POLES

Route of infestation	Alhambra	Los Angeles	San Diego	Alhambra	Total
1. Shallow check	3	7	8	13	31
2. Deep check	0	0	0	4	4
3. Knot	1	0	0	0	1
4. Upper gain	1	3	2	2	8
5. Lower gain	0	1	4	8	13
6. Side gain	1	0	0	8	9
7. Spur mark	1	0	0	0	1
Roof	1	0	0	1	2

Paths of infestation in buildings.—Observations made in the field during the swarming season, together with information secured from an experimental house (p. 234) and from investigations of infested houses, indicate that the roof of a building is most frequently chosen by pairs seeking an entrance into the wood. This does not imply that parts of the superstructure between plate and sill do not become infested by royal pairs, but rather that many more infestations occur above the plate than below it. One reason for this is that the alates usually make their flight at a sufficient elevation to bring them in contact with roofs of houses. However, a small percentage of the alates fly distances of but five to eight feet, and many which fly more freely never attain a height of more than seven or eight feet, or at the most ten to twelve feet. It is chiefly these which colonize the lower portions of buildings, although the results secured from the experimental house (p. 234) indicate that some newly mated pairs, pairs which mated on the sheathing inside the roof, for instance, may run along a studding to its base in search of a place to enter the wood, and become established there. This seems to be a relatively rare occurrence, however.

Behavior at the site of infestation.—Having attained sufficient height, from forty to sixty feet, the typical alates wing away until a structure is encountered, such as a pole or a building, on which they alight, lose their wings, mate, and enter the wood.

Let us follow the typical behavior of a newly mated pair of common drywood termites on the roof of a residence, first recalling the high excitability and nervous tension which began when, as alates, they emerged from the colony, and which continued through the flight, the loss of wings, and the encounters with other reproductives, until the pair met each other.

Inaction has no part in the sequence of events. Apparently the first instinct is to move, and the pair race across the roof, king following queen closely, over the gaps between the shingles, until almost the entire length of the roof has been traversed. Suddenly the queen halts to investigate an abrasion in a shingle, but it does not detain her long and she goes on to a small crack and then to a small, splintery crevice. Each time the king is brought up with a jerk, but rushes to the queen's side and apparently aids in the inspection, whereupon the queen rushes away again, leaving behind, for the moment, the king, who lingers to complete inspection of the wood.

The two rush about in this manner until they reach the edge of the roof, which, however, does not deter them. They run over it, along the edge and under-surface of the shingles to the sheathing, and disappear between shingles and sheathing. One might suppose that they have permanently disappeared, but soon they reappear from an opening between two members of the sheathing layer, apparently intent upon retracing the course that they pursued across the roof. However, after several minutes of seemingly aimless wandering in and out, they again disappear between shingles and sheathing and are not seen again.

If observations are made at the height of the swarming season numerous such pairs may be found on a roof near swarming colonies. Let us visualize a pair on the inside of the roof running along the ridgepole. At once they encounter more obstacles because of the regularly spaced rafters, but they utilize small cracks between rafters and ridgepole, into which they disappear, shortly to emerge on the other side. Continuing along the ridgepole, they may run over the next rafter, detour long enough to investigate a foot or so of its length, then return to the ridgepole, where a knot is given scant attention. A small crack causes a brief pause, but they contine their nervous searching, usually at last to find a retreat between rafter and sheathing. Other pairs may be found on the rafters, on the plate, on the sheathing, or occasionally a pair is seen to run along a studding almost to the floor.

The greater number of royal pairs within the roof than on the surface of the shingles outside, together with the peculiarly agitated actions of newly mated pairs on the surface of the shingles, indicate that the sunlight which attracted them so strongly during emergence from the colony, during flight, and even during loss of wings, now repels them. The distracted running about which has been described seems to be the result, partly, of a newly developed negative reaction to light (negative phototropism), and almost certainly of a tendency to enter small crevices (positive thigmotropism), together with a response to the odor of wood.

Cracks and crevices in the roof of a building of a nature to invite royal pairs are numerous. First of all, there is the layer of shingles that covers the roof, with cracks between individual shingles and between the overlapping rows of shingles. Strangely enough, newly mated royal pairs seem not to be attracted by the layer of shingles as a possible point of infestation. Perhaps the shingles are too thin, or the effect of the direct sunlight is too great. How-

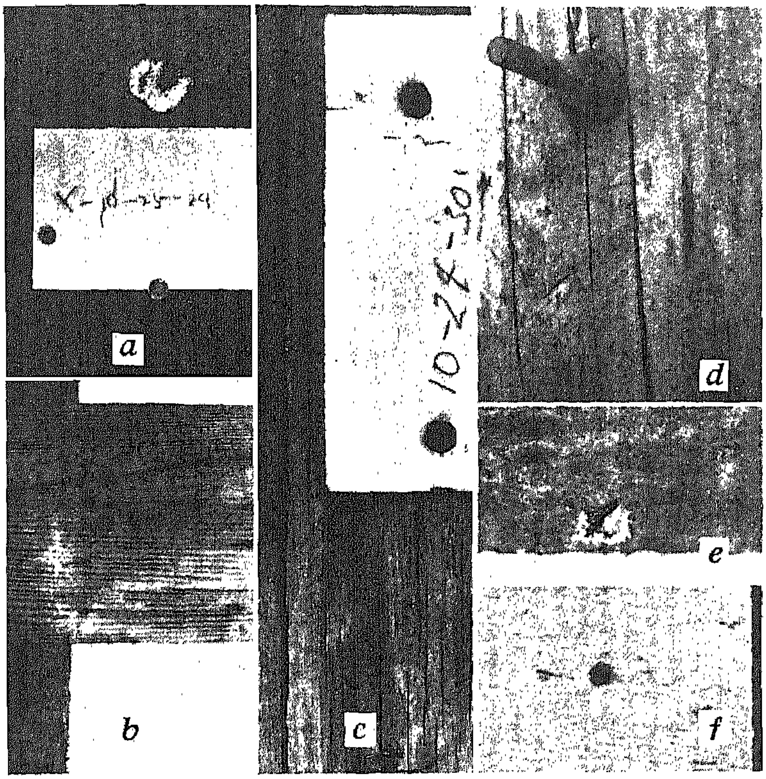


Fig. 77. Photographs of the work of colonizing pairs of *Kalotermes minor*, the common dry-wood termite. *a.* The excavated woody tissue which accumulates until the termites have completed entrance into the wood and sealed themselves in, when it is massed about the plug to the royal cell. *b.* An upright in one of the muslin enclosures used for field experiments, showing four nail holes, in each one of which a royal pair was effecting an entrance into the wood. *c.* Surface of a pole showing checks which serve as points of entry for colonizing pairs. A remnant of the material excavated by such a pair during entrance remains attached to the right side of the large check. *d.* Surface of a cedar pole showing the type of check chosen as a point of entry. A pair was digging into the larger check when the photograph was taken. *e.* Entrance of a colonizing pair into the surface of a board in a pile. Note the bulwark of frass which enclosed them in a cell between the boards. *f.* Surface of board showing one of very few cases encountered of direct entry of a colonizing pair into the surface of a board. The sealed entrance is a small dark fleck which is above and somewhat to the right of the nail head. The board was part of a brace in the framework of an experimental enclosure.

ever, between shingles and sheathing abundant protection is afforded, and observations in the experimental house show that the royal pairs take full advantage of it while they carve a way into the sheathing.

Further aid and protection are to be found in the crevices between sheathing and rafters, between rafter ends and plate, between rafter ends and ridgepole, between plate and studding ends, between studding and siding, and between siding and corner boards, to cite some of the possible and probable paths of infestation into a building.

Valuable information on behavior in connection with the infestation of buildings was obtained from an experimental house constructed at Alhambra (p. 234). One path of infestation favored by newly mated pairs in this house was the joint between rafter and ridgepole where they effected an entrance into one or the other. While the darkness and protection within the roof of a building appear to make this location more desirable to colonizing pairs than the exterior of the building, some infestations do occur on the outside. One such infestation was noted at the joint between a siding member and the corner board.

In comparatively few cases does the royal pair penetrate directly into the surface of a board without the aid and protection of crack or crevice. Such cases do occur, however, as illustrated in figure *77f*. In another instance, a royal pair carved a way directly into a brace in the framework of one of the experimental muslin enclosures. In both instances the surface of the board was rough and sufficiently ridged to give some aid to the royal pair. A nail hole also is one of the most easily accessible paths of infestation, and, possibly because it relieves the termites of considerable digging, they quickly make a selection of such a point of entrance, when encountered (fig. *77b*).

The experimental house was scarcely better for observations in connection with infestation by reproductives than the frame of the muslin enclosure, with its numerous cracks between the uprights and the stringers, and between the stringers and the braces, which many newly mated pairs entered. This was also true of the framework of the enclosures for the field experiments in connection with the infestation of poles by reproductives.

AN EXPERIMENTAL HOUSE

To determine the method of entrance into houses by colonizing pairs of *Kalotermes minor* an experimental wood frame house was made and set on a tile foundation in a muslin enclosure (fig. *78a*). The house was 10 feet long, 6 feet wide, and 8 feet high. It was divided into longitudinal halves, one of which was wood-sided, the other stuccoed. Construction was typical for southern California (fig. *78b, c*). Each half was separated by muslin.

The dimension pieces in both halves of the building and the sheathing and flooring were of Douglas fir. The siding was of redwood, part of the finish material and part of the shingles also were of redwood, part of the shingles of red cedar, and the doors and windows of sugar pine. A door was placed in one end of each half of the building (fig. 78), and a window with a single sash was placed in each side.

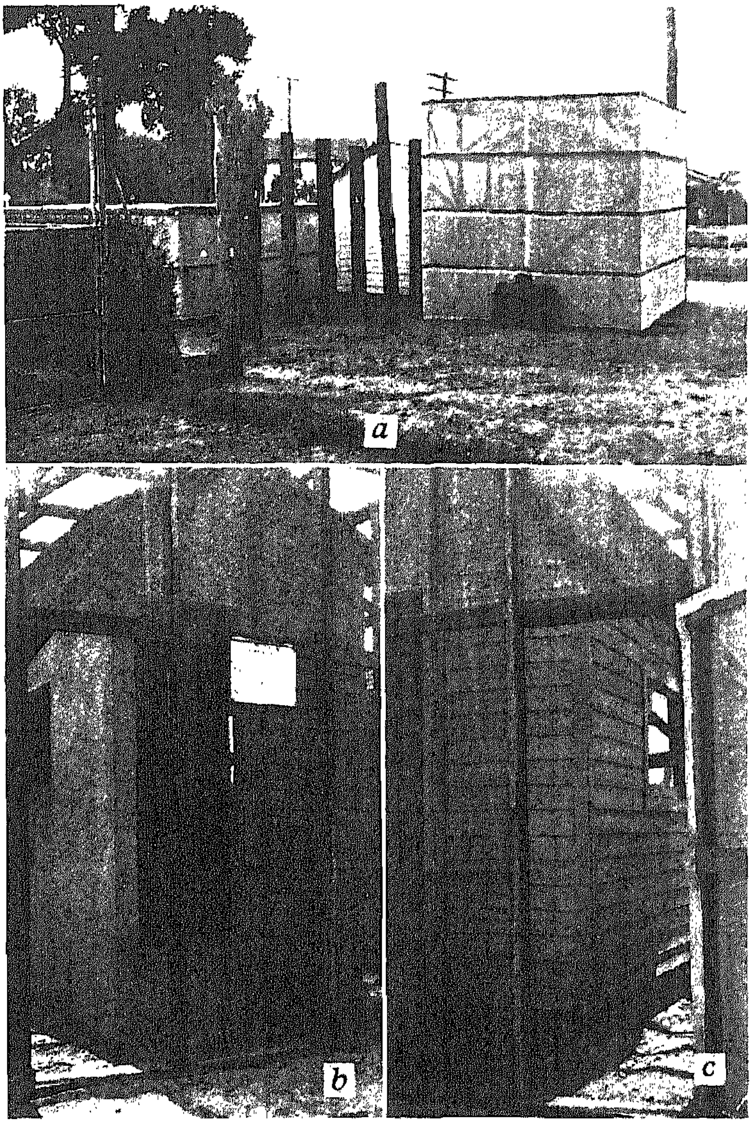


Fig. 78. Photographs of the enclosed experimental house, half stuccoed, half wood-sided. *a*, The house and enclosure and, to the left, a low muslin enclosure used in experimental infestation of poles. *b*. With the door of the enclosure opened to show the stuccoed side. *c*. With the door opened to show the wood-covered side.

In the fall of 1930, just before the swarming season of the common dry-wood termite, thirteen pole tops containing alates were placed between the muslin enclosure and the building, equally spaced as regards the two halves of the building. During the swarming season alates emerged from the infested tops, and while many of them escaped through the muslin of the enclosure, some mated and infested the building.

On July 28, 1931 the east one-third of the roof running over both halves of the house was removed and dissected to secure information regarding the resistance of the stuccoed half in contrast to the wood-sided half. The third of the roof was removed to the ground, the shingles removed from the sheathing, and finally the sheathing removed from the rafters on the two halves. Wings of colonizing reproductives were found between the layer of shingles and the sheathing. Places where colonizing pairs had entered the sheathing were indicated by the accumulations of granular woody fragments and by the plugs with which the pairs had sealed themselves in. These were found in both sections of the portion of the roof that was removed. This was to be expected in view of the fact that, so far as the roof was concerned, there was no difference between the two halves of the building, and since both halves were subjected equally and at the same time to flights of alates that emerged from the infested tops of poles. Colonizing pairs did not enter the shingles, but numerous wings were found between the shingles, indicating that some termites had dealated there, which corroborates observations previously made.

Following dissection of the roof, the gable and the studs at the east end of both parts of the building were removed, with part of the siding on the east end of the plain portion, part of the siding, sheathing, and studs at the southeast corner of the plain section, and some of the studs at the northeast corner of the stuccoed part. As was expected, a marked difference was found between the stuccoed and the plain frame parts of the house, due to the protection afforded by the stuccoing. No infestations were found in the frame of the stuccoed half, while five pairs of termites, in addition to two pairs in the roof structures, were found to have entered the frame of the plain half, as follows:

Between sheathing member and gable end rafter near ridgepole	1 pair
Between sheathing member and second rafter from east end	1 pair
Between gable and rafter, studding and ridgepole	2 pairs
In nail hole of gable end studding	1 pair
Between plate and rafter	1 pair
Between siding and stud	1 pair

Such an experiment, while incomplete, does give significant indication of the correlation between exposure of wooden members and extent of infestation by the dry-wood termite.

DRY-KILNED vs. GREEN LUMBER

Questions as to the relative resistance of dry-kilned and green lumber to newly mated pairs of the common dry-wood termites led to a field experiment during the swarming season of 1930 which was carried out as follows:

Twenty green Douglas fir boards, each 1 inch x 4 inches x 18 inches, were arranged in two tiers on a tile pedestal which stood in a small muslin enclosure, and twenty kiln-dried Douglas fir boards, similar in size to the green ones, were placed in two tiers on another tile pedestal within the same enclosure. Four pole tops containing alates of the common dry-wood termites were also arranged in the enclosure.

When the alates emerged from the infested pole tops, some of them lost their wings and mated on the tiers of dry-kilned and green boards. Nine pairs entered the wood, and of these but one pair entered the dry-kilned wood. No further specific data in regard to the relative resistance of dry-kilned and green lumber are available, but field observations indicate that newly mated reproductives prefer green lumber.

RATE OF ENTRANCE INTO WOOD

Selection of a place to enter the wood having been made, the pair of common dry-wood termites labor industriously. At first they work side by side, assembling the granular bits of wood which they have carved from the entrance. When it is no longer possible for both to dig at the same time, they alternate at the task until the hole is large enough to receive them, whereupon they enter and seal the passage. Due to the motion of the jaws, the woody bits are rolled backward in granular heaps to the maxillary palpi, and by them backward until the termite kicks them out of the burrow. As the king and queen change places in the course of making an entrance, the woody tissue is pushed away and heaped about them in a circle so as to give them space in which to work.

Numerous field observations made during 1929 and 1930 indicate that, with favorable conditions, complete entrance is effected in about forty-eight hours. That various factors, such as suboptimum temperature, mechanical disturbance, and probably others not known, function to delay effective entrance is indicated by the results of certain field experiments and observations. For example, the rate of entrance into piled lumber was observed for five pairs which supposedly swarmed on October 7, 1930. Examinations were made on October 9, 11, and 16. On October 9 the holes made by three of the pairs were ¼ inch deep, that of one was just started, and one was almost deep enough to hold both reproductives. Observed again on October 11, no progress was noted, while on October 16 two entrances were sealed, two were complete but unsealed, and one was ¾ inch deep. Correlated with this slow rate of penetration were low temperatures. The maximum temperature on the supposed day of flight, October 7, was 83° F., but the next six days it was 70°, 69°, 70°, 73°, 76°, and 78° F., respectively.

An experiment carried out later in the same month, October 23 to 31, gave similar results. Here the pairs were infesting boards in tiers. At the end of eight days none of the nine pairs observed had completely sealed themselves in. The temperatures at the time of this experiment were much higher, 93°, 85°, 74°, 79°, 85°, 91°, and 92° F., respectively. The delay seems attributable to the disturbance of lifting the boards between which the pairs were working, which perhaps also made for unfavorable drying.

RATE OF INCREASE IN THE COLONY

The life of the Committee was too short to obtain extended information on the rate of mortality in infesting pairs, times and rate of egg laying, lengths of instars, normal rate of increase of the colony, etc. As a result, the figures here presented must be considered as not necessarily representing the normal life cycle. Some of the factors which probably tended to render the mortality of infesting pairs much higher than normal and to slow down egg laying and individual development were (1) injury from handling; (2) ill effects from keeping alates in a dry atmosphere much longer than is normal; (3) retardation of entry beyond the normal time; and (4) abnormal factors in the artificial environment, such as (a) large spaces difficult to seal, (b) exposure to high temperature, due to small size and exposed location of wood pieces used, and (c) reduction of moisture below optimum, for the same reason.

MORTALITY IN COLONIZING PAIRS

The proportion of pairs actually making entry is relatively low, and of these it is uncertain what percentage is successful in establishing colonies. The fact that favorable structures of considerable age in heavily infested areas contain relatively few colonies (p. 249) seems to indicate that only a few such pairs are successful. The early figures (Table 17) obtained from three very different situations, the so-called "block cells" and "dowel cells" in the laboratory, and parts of the experimental house, seem to indicate a high rate of mortality.

TABLE 17

MORTALITY IN COLONIZING PAIRS

Location	Colony started	Opened	Pairs alive	Pairs dead	Work done		
					None	Slight	Normal
Block cells	Oct. 1930	Nov. 25, 1930	2	3	3	2	0
Block cells	Oct. 1930	Jan. 1, 1931	2	4	5	0	1
Block cells	Oct. 1930	Jan. 23, 1931	1	0	0	0	1
Block cells	Oct. 1930	Nov. 7-10, 1931	3	97	68	24	8
Dowel cells	Oct. 1929	Nov. 18, 1929	1	4	4	0	1
Dowel cells	Oct. 1929	Dec. 7, 1929	0	3	3	0	0
Dowel cells	Oct. 1929	Nov. 15, 1930	0	3	3	0	0
Dowel cells	Oct. 1929	July 11, 1931	2	27	18	10	1
Experimental house	Oct. 1929	July 28, 1931	0	8	0	5	0

For the block cell a ⅛-inch hole was bored for 1¼ inches into one end of a block 8 inches x 3 inches, cut so as to include all of the sapwood of a sector of a red cedar pole and a minimum of heartwood. The pair of termites were placed in a 1-dram vial, which was then inverted over the hole. Under these conditions they usually sealed themselves in without digging into the wood.

The dowel cell was made by stoppering a 1-dram vial with a wooden dowel 2 inches x ¼ inch, with a hole ⅛ inch in diameter and 1 inch in depth in the end towards the vial. The pair were introduced into the vial, which was then inverted. The hole in the dowel simulated a royal cell, and was used as such by the pair in most cases without digging farther into the wood. When they had sealed themselves in, the dowel was removed from the vial and fitted snugly into a hole in one end of a piece of Douglas fir scantling 18 inches long x 2 inches square.

In both types of cell the necessary handling and the fluctuations in the moisture content of small pieces of wood are obvious unfavorable factors.

The colonizing pairs in the experimental house entered normally at the swarming season, hence eliminating the factor of handling. The exact locations of these pairs are given on page 236. The only obvious explanation of the high death rate noted here was the high temperature and resultant low moisture content.

Recent results of an attempt to eliminate all such harmful factors give a much higher percentage of viable pairs. Of thirty-eight pairs started in September, 1931, thirty were alive and active in July, 1932.

RATE OF INCREASE IN THE INCIPIENT COLONY

Attempts to determine the rate of increase in the incipient colony were hindered and the results modified by the same experimental difficulties mentioned in connection with per cent of viability. Table 18 gives some idea of the actual increases in incipient colonies under field and laboratory condi-

TABLE 18

RATE OF INCREASE IN INCIPIENT COLONIES

Location	Age when opened	Increase
	months	
1. Redwood plank	13	5 nymphs
2. Cedar pole	14	2 nymphs
3. Cedar pole top	9	5 nymphs, 1 soldier
4. Cedar pole top	9	8 nymphs, 1 soldier
5. Cedar pole top	9½	5 nymphs, 1 soldier
6. Cedar pole in field	9½	20 nymphs, 1 soldier, 5 eggs
7. Cedar pole in field	9½	5 nymphs
8. Laboratory	9	2 nymphs
9. Laboratory	9	5 nymphs, 2 eggs
10. Laboratory	10	3 nymphs, 1 soldier
11. Laboratory	8	1 egg
12. Laboratory	5	1 egg
13. Laboratory	10	3 nymphs, 2 eggs
14. Laboratory	7	1 egg
15. Laboratory	8	1 nymph, 6 eggs
16. Laboratory	6½	2 eggs
17. Laboratory	10	1 egg
18. Laboratory	8	1 nymph, 3 eggs
19. Laboratory	8	2 nymphs
20. Laboratory	6	1 egg
21. Laboratory	6	1 egg
22. Laboratory	6½	1 egg
23. Laboratory	6½	1 egg

tions. The first seven colonies were established during the swarming season of 1929, presumbaly about the middle of October, the others during the swarming season of 1931. In the first seven of these cases the pairs entered without delay or handling. The wide range in rate of increase in these colonies indicates the importance of certain undetermined factors, probably temperature, vicissitudes of the period of swarming and infestation, and condition of alates at time of infestation. In view of the great discrepancy between No. 6 and the other colonies, it seems probable that this colony was the result of coalescence of two or more incipient colonies.

Table 19 gives the population of six colonies, all twenty-three months old, in cedar poles in the experimental enclosure. Here, again, under seemingly normal and uniform conditions, there is great variation, from no progeny at all to a group of thirty-nine individuals.

TABLE 19

CONSTITUTION OF YOUNG COLONIES

Reproductives	Soldiers	Nymphs
2 primary	1	38
2 primary	1	4
1 primary	0	3
1 secondary	....	....
2 primary	0	5
2 primary	0	0

In this connection the high percentage of failures should be recalled. Out of a total of fifteen pairs which entered the pole tops in the fall of 1930 only eight were alive when the poles were dissected in late September, 1932. Evidently, therefore, the success or failure of a colonizing pair or of a young colony, and the rate of increase in the colony, depend upon factors yet to be determined, which may vary sufficiently under seemingly uniform conditions to allow for all gradations between early death of the infesting pair, on the one hand, and the development, within two years, of a colony of forty individuals, on the other. Those factors which suggest themselves as being involved are (1) the condition of the infesting pair; and (2) the temperature conditions, which might vary considerably on different sides of the same pole.

SIZE AND CONSTITUTION OF COLONIES IN POLES

Dissections of poles have given the best information as to the constitution of, and the extent of damage by, mature colonies of the common dry-wood termite. Active colonies were found in the lower part of the pole as often as in the top. The burrows of the various colonies were clearly separated, except in badly infested poles, in which as many as fourteen active colonies per pole have been found. Here it was often impossible to make out the limits of the individual colonies. Besides those in the pole itself, active colonies have been found in crossarms, with no extension into the body of the pole.

In dissecting an infested pole the butt was removed and the body of the pole sawn into lengths of from 16 inches to 2 feet. Each section was split up into small pieces on a canvas and the termites collected and preserved in alcohol for counting. The pellets were also collected in some instances. Certain general information obtained from ten such dissections appears in Table 20.

TABLE 20

MATURE COLONIES OF THE COMMON DRY-WOOD TERMITE BASED ON DISSECTIONS OF INFESTED POLES

Pole No.	Length of pole in feet	Age in line in years	Location of colonies	Number of active colonies	Number of incipient colonies	Reproductives in active colonies	Soldiers	Nymphs	Ratio of soldiers
1	35	13–16	Throughout	3	0	5	36	1,956	1:53
2	30	16	Bottom	2	2	3	67	2,197	1:33
			Top	1	3	1	4	75	1:19
3	30	16	Bottom	5	6	5	100	4,520	1:45
			Top	1	2	1	4	175	1:44
4	25	37	Throughout	19	0	24	519	10,935	1:21
5	30	12–15	Throughout	3	2	9	97	3,392	1:35
6	25	40	Throughout	2	0	3	45	1,655	1:37
7	45	15	Throughout	3	3	3	39	1,473	1:38
8	35	15	Bottom	1	3	1	98	2,647	1:27
			Top	2	0	2	98	2,500	1:25
9	30	10–12	Throughout	1	0	1	46	800	1:17
10	25	37	Crossarm	1	0	2	1	55	1:55
			Total	44	21	60	1,154	32,380	1:28

During dissection observations were made of the location and extent of each colony, and the nature and location of the passages in the wood. The passages were most extensive in the sapwood, which, in a badly infested pole, was completely riddled. Passages were found also in the heartwood, but seldom were they as extensive in this region as in the sapwood.

An attempt was made to determine the age of the colonies found in each pole. The criteria used were the size of the queen, the number of individuals in the colony, and the extent of its workings. Observations made on incipient colonies indicate that the queen shows no important increase in length during the first year, but increases about 0.8 mm. during the second year, and apparently about the same the third year. Beyond three years no definite information is available as to the annual increment in length. It has been assumed to be the same, however. On this admittedly insecure basis the age of colonies has been estimated.

Table 21 brings out two interesting points, first, the relative youth of the colonies in proportion to the age of the poles and, secondly, the high percentage of incipient colonies. Only a single colony was found which was estimated to be more than eight years of age, and only two above six years of age.

If correct, this points, of course, to a relatively recent flare of infestations in poles, and perhaps to increasing damage from *Kalotermes minor*. More detailed findings for certain poles follow.

TABLE 21

INFESTATIONS OF POLES BY DRY-WOOD TERMITES

Pole No.	Age of pole in years	Estimated age of colonies							
		Incipient	2 years	3 years	4 years	5 years	6 years	8 years	14 years
1	13–16	0	....	2	1	....	....	....	....
2	16	5	....	1	1	....	....	1	....
3	16	8	1	....	3	1	1	....	....
4	37	0	....	6	1	7	4	....	1
5	12–15	2	3	....	....	....	....	....	....
6	40	0	....	2	....	....	....	....	....
7	15	3	....	2	1	....	....	....	....
8	15	3	....	2	....	1	....	....	....
9	10–12	0	....	1	....	....	....	....	....
		21	4	16	7	9	5	1	1

Case 1.—Dissection of pole 40849H at Los Angeles, California (No. 1 in Table 20), November 23, 1928; red cedar telephone and telegraph pole, 13 to 16 years in service. This was a 35-foot pole. Judging by the three primary queens obtained during dissection of the pole, the termite population was represented by 1 four-year-old colony and 2 three-year-old colonies which had the following probable organization (Table 22):

TABLE 22

ORGANIZATION OF COLONIES IN POLE 40849H

Colony No. 1		Colony No. 2		Colony No. 3	
4-year-old queen	1	3-year-old queen	1	3-year-old queen	1
4-year-old king	0	3-year-old king	1	3-year-old king	1
Soldiers	16	Soldiers	10	Soldiers	10
Nymphs	756	Nymphs	600	Nymphs	600
	773		612		612

Total number of termites, 1,997.

Injury to the pole consisted of riddling the sapwood with passages and penetrating the heartwood, a destruction of wood that, judging by the age of the oldest primary queen, dated back to the fall of 1925. During the swarming season of 1925 a colonizing pair of the common dry-wood termite infested the pole and from them colony No. 1 developed, if we are correct in estimating the age of the primary queen in this colony. During the swarming season of 1926 two colonizing pairs became established in the pole, and from them colonies 2 and 3 developed.

Case 2.—Dissection of pole A2812 at San Diego, California (No. 2 in Table 20), March 11, 1930; red cedar power line pole, 16 years in service. This was a 30-foot pole, the butt of which, 4 feet long, was removed before the body of the pole was cut into 13 2-foot lengths.

Beginning at the ground line, there was 1 eight-year-old colony and 1 four-year-old colony in the first 10 2-foot lengths. The two colonies were so close together that it was difficult to distinguish the passages one from the other; in fact, it was impossible, when the dissection was being made, to separate the two colonies. The population of the colonies was as follows: 1 eight-year-old queen, 1 four-year-old queen, 1 secondary queen, 67 soldiers, and 2,197 nymphs—a total of 2,267 termites.

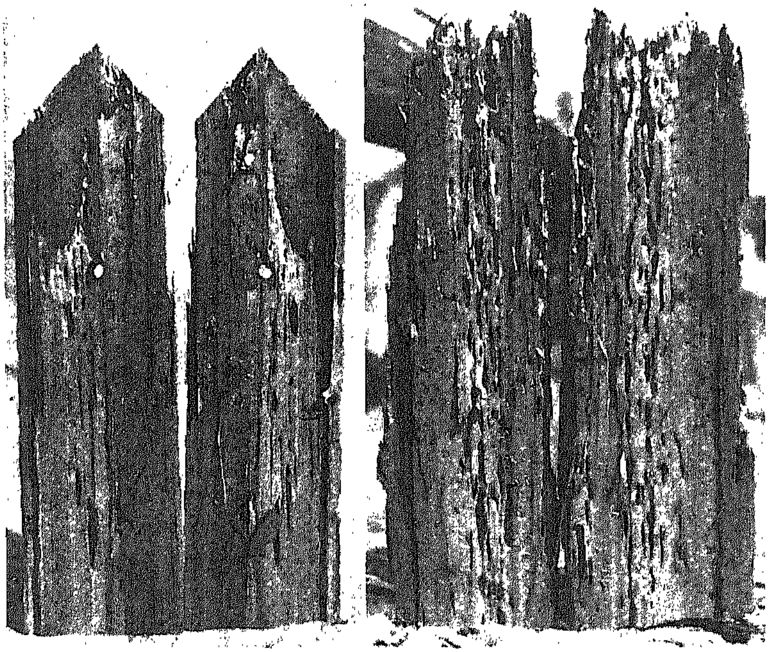

a *b*

Fig. 79. Photographs showing damage done by dry-wood termites, *Kalotermes minor*, in the pole discussed in Case No. 2. *a*. The top split open to show the work of one colony. *b*. The lower part of the body of the pole split open. Note that the pole was nearly severed at the ground line.

These colonies had riddled the sapwood and penetrated the heartwood, resulting in serious injury to the pole; in fact, practically severing it at the ground line (fig. 79*b*). The older colony, whose workings were most extensive in the ground line piece, was mainly responsible for the destruction of the pole. However, the colony of the four-year-old queen, which entered in the fall of 1925, aided the older colony greatly in destruction of the wood. The wood of the pole in piece No. 1, the ground line piece, was so thoroughly riddled with termite passages that it became necessary for the termites to plug up large openings that appeared in the pole from natural causes. The plugs consisted of a mixture of pellets, partially chewed wood, woody refuse, and particles of earth.

There were also 2 incipient colonies in pieces 1 to 10, that is, pairs which became established in the pole during the swarming season of the common dry-wood termite in the fall of 1929, but which were without progeny at the time the pole was dissected.

One three-year-old colony was found in the top 6 feet of the pole. The population of this colony consisted of the queen, 4 soldiers, and 75 nymphs. This colony had penetrated the sapwood with passages that extended deep into the heartwood, and while the resulting injury was not so serious as that done by the two large colonies in the lower part of the pole, it was appreciable (fig. 79*a*). In addition to the three-year-old colony, 3 incipient colonies, as yet without progeny, had become established in the top of the pole during the swarming season in the fall of 1929. The total population of this pole was therefore about 2,353 termites, and the pole contained 6½ pints of pellets.

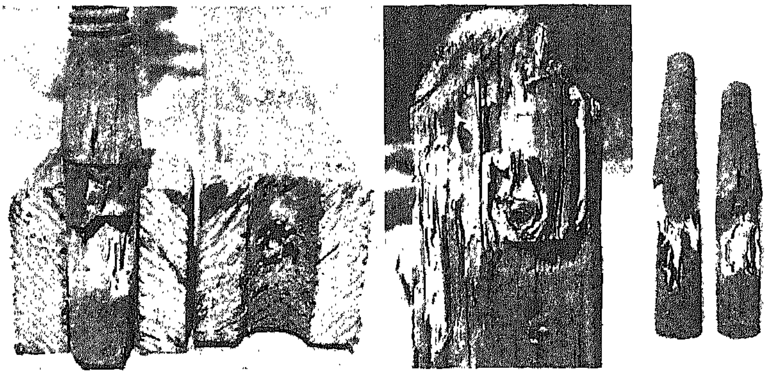


Fig. 80. Further examples of damage encountered in case 2 (p. 243). *a*. Cross sections of the crossarm with one pin in place. *b*. The top of the pole, partly dissected. *c*. Two of the four infested pins.

The crossarm contained an infestation separate from the colonies in the body of the pole, as shown by the absence of intercommunicating passages at the gains (fig. 80*b*). The crossarm was dissected only sufficiently to show that the termites had penetrated it extensively (fig. 80*a*) and had practically destroyed two of the four pins (fig. 80*c*).

Case 3.—Dissection of pole A2856 at San Diego, California (No. 3 in Table 20), March 12, 1930; red cedar power line pole, 16 years in service. This 30-foot pole was sawn into 13 2-foot lengths after removal of the 4-foot butt. The termite population was located in two distinct parts of the pole. In pieces 1 to 3, inclusive, commencing with the ground line piece, there were 1 six-year-old colony, 3 four-year-old colonies, 1 two-year-old colony, and 6 incipient colonies without progeny. The probable numerical organization of each colony in pieces 1 to 3, inclusive, is given in Table 23.

Injury to the pole consisted of riddled sapwood, with passages penetrating to the heartwood, in much the same manner and to about the same extent as in pole A2812. In fact, poles A2812 and A2856 were removed from an alley line within one block of each other, and their histories are much the same, although more colonies, and consequently more termites, became established in A2856 than in A2812.

TABLE 23

POPULATION OF THE FIVE COLONIES IN THE LOWER PORTION OF POLE A2856

	Colony No. 1	Colonies Nos. 2-4	Colony No. 5
Queens	1	1	1
Soldiers	36	20	4
Nymphs	1,650	895	185
	1,687	916	190

Total number of termites in the five colonies, 4,625.

Judged by the age of the primary queen of the oldest colony, the original infestation of this pole dated back only to the fall of 1923. This colony was mainly responsible for the destruction of the pole, but it was ably assisted by the two other large colonies in the pole.

In pieces 4 to 10, inclusive, of pole A2856, no termites were found when the pole was dissected, but 1 small colony, considered to be five years old on the basis of the size of the queen, was found in pieces 11 to 13, inclusive. In addition, there were in these pieces 2 incipient colonies without progeny.

The one five-year-old colony in pieces 11 to 13 included 4 soldiers and 175 nymphs. Injury to the top of the pole by this colony consisted of penetration of the sapwood and the heartwood, much like that of the colony in the top of pole A2312. The total termite population of the pole was 4,821. Six and one-half pints of pellets were collected during the dissection of the pole.

Case 4.—Dissection of pole 930 at Westport, Mendocino County, California, March 25, 1930; redwood sucker telephone and telegraph pole in Shore Line Lead, 37 years in service. This 25-foot pole was sawn into 10 2-foot lengths following removal of the butt, which was originally 5 feet long, but which had in part rotted away.

The termite population of the pole consisted of over 11,000 individuals. Aided by the many nymphs, whose number it is impossible to estimate, which had escaped as alates at various times during the years of infestation, they had destroyed 30.5 per cent of the pole, based on measurements by submersion. The extensive sapwood of the pole was so completely eaten away that it was little more than a honeycomb; the outer shell, however, was intact. The passages also thoroughly ramified the heartwood. Dissection of each 2-foot length into which the pole had been cut indicated that 19 colonies were present, the oldest of which was fourteen years old, but their passages were so intimately associated, if not actually communicating with each other, that the colonies could not be critically delimited. The probable constitution of each colony, based on the ages of the 19 primary queens secured, is given in Table 24.

Thus, there was 1 very large fourteen-year-old colony in this pole, 4 large six-year-old colonies, 7 large five-year-old colonies, 1 four-year-old colony, and 6 three-year-old colonies. About 6 pounds of pellets were collected, and, as pointed out above, the termites had destroyed about 30 per cent of the volume of the pole.

TABLE 24

POPULATION OF THE NINETEEN COLONIES OF TERMITES IN POLE 930

Colony No.	Estimated age, years	Queens	Kings	Secondary queens	Soldiers	Nymphs	Total
1	14	1	0	3	109	1,110	1,223
2–3	6	1	0	....	60	811	1,744
4–5	6	1	0	....	55	811	1,734
6–9	5	1	0	....	20	570	2,364
10–12	5	1	0	....	10	570	1,743
13	4	1	0	....	10	436	447
14–16	3	1	1	....	10	359	1,113
17–19	3	1	1	....	10	358	1,110

Total termite population, 11,478.

Case 6.—Dissection of hewn redwood signal line pole 40 years in service at Quarry Siding, 12 miles east of San Diego, California; this 25-foot pole was sawn into 11 2-foot lengths following removal of the 3-foot butt. Three reproductives were secured during dissection of the pole, and a total of 1,703 termites. The size of the reproductives indicated that they belonged to young colonies, probably three years old. If this is correct, the infestation dated back but 3 years, although the pole had been in service for 40 years.

Number of alates.—The dissections reported above were made at times when alates were not present in the colonies. No counts are available to show the number of alates produced by a colony of known population. Three cases follow, however, which give some idea of the number of alates produced in a single pole. Cases 1 and 2 supposedly involve a single colony each, while case 3 probably represents several colonies.

Case 1.—Dissection of red cedar power line pole at Riverside, California, September 26, 1930. This 40-foot pole, well infested with the common drywood termite, contained 593 alates.

Case 2.—Dissection of red cedar power line pole at San Diego, California, September 19, 1930. This 40-foot pole was well infested with the common drywood termite, and 403 alates were taken from it.

Case 3.—Dissection of red cedar telephone and telegraph pole at Los Angeles, California, September 4, 1930. This 30-foot pole was dissected for other purposes, but was found to contain 2,384 alates.

TYPES OF INFESTATIONS BY THE DRY-WOOD TERMITE IN BUILDINGS

Twenty-one buildings in central and southern California infested with the common dry-wood termite, *Kalotermes minor,* were critically examined with a view to determining the location and extent of the infestations. The buildings were known to be infested, but were not otherwise selected, and hence give some idea of the damage generally done in buildings by this termite. The location of the cases was determined by chance and opportunity, and has no relation to the density of termite population in different areas, and hence is not given here except in certain cases discussed in detail. Some of the buildings inspected were infested also with the western subterranean termite and the damp-wood termite, but these infestations are not here discussed. None of the twenty-one buildings was taken to pieces, but the examination of each was in the nature of a diagnosis of the infestation, in which its extent, the structural members affected, and its degree were determined.

The presence of an infestation was usually detected by the accumulations of pellets under the infested members, as, for example, on the floor of the attic, if the infestation was in the rafters of the building, or on the sill, if the infestation was in the studding. The location of infestations was also determined in some cases by sounding the member with a screwdriver, hammer, or chisel. The extent of the infestation, the members affected, the seriousness of the infestation, and the number of separate colonies or groups of colonies of the common dry-wood termite involved were then determined as follows:

(1) Further accumulations of pellets were sought in the vicinity of the pile which led to detection of the infestation.

(2) The infested member under which a pile of pellets was found was sounded in an effort to determine the extent of the infestation.

(3) The infestation was traced in a similar manner to other members until its complete extent, the number of structural members involved, the seriousness of the infestation, and, where possible, the number of colonies involved, were determined as thoroughly as possible.

(4) Occasionally an infested member was broken or cut open.

(5) Having determined the extent of one colony, other parts of the building were inspected in a similar manner.

(6) A collection of termites was made from an infested building, but as a matter of record only, and in no case was an effort made to secure all of the individuals in the colony, as was done in dissections of poles (p. 241). However, it was usually possible to determine the number of separate colonies in the infested structure while tracing the infestation as outlined above.

In cases 2, 18, 19, and 20 (Table 25) a departure was made from the usual method of determining the extent of an infestation and the number of colonies. In cases 2 and 18 a method for impregnating passages of the common dry-wood termite with a poisonous liquid used by a prominent termite control operator of San Diego, California, was adopted for tracing the infestations. This method proved particularly valuable in giving information as to the number of colonies and the limits of each colony in the infested structure.

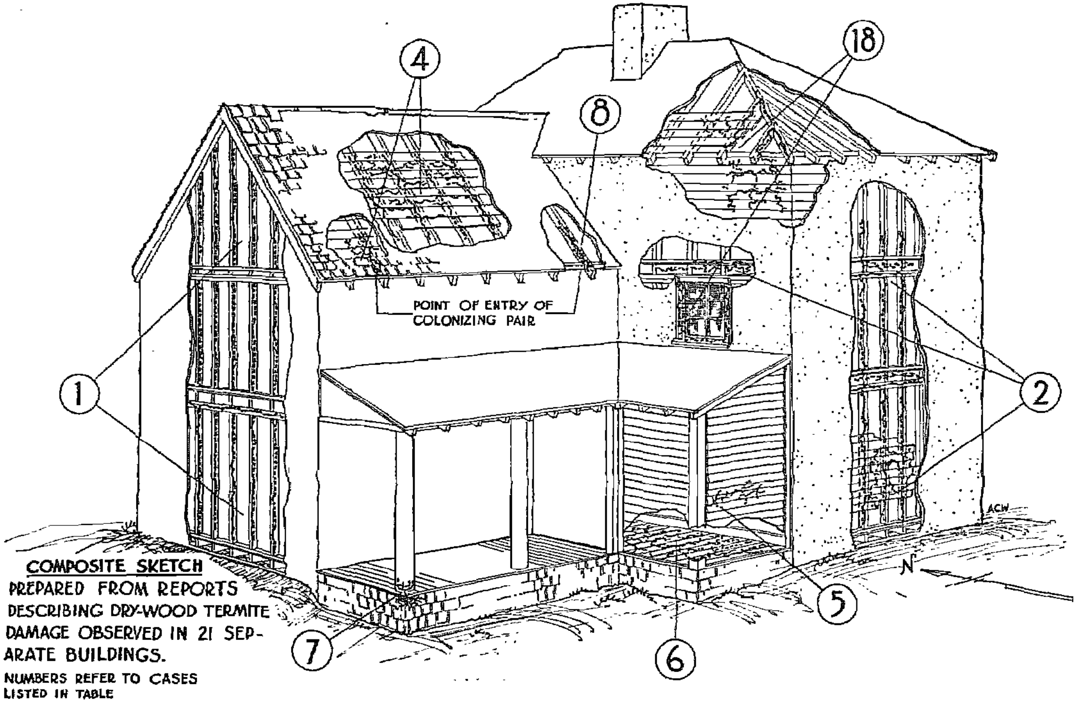

4
8
18
POINT OF ENTRY OF COLONIZING PAIR
1
2
ACW
N
COMPOSITE SKETCH
PREPARED FROM REPORTS DESCRIBING DRY-WOOD TERMITE DAMAGE OBSERVED IN 21 SEPARATE BUILDINGS.
NUMBERS REFER TO CASES LISTED IN TABLE
7
6
5

Fig. 81.

In cases 19 and 20 the course of each infestation was traced by blowing a poisonous powder into the termite passages (chap. 38), and later observing where the termites destroyed by it were located. This method was valuable for determining the extent of the infestation and the number of colonies involved.

So far as possible, accurate information regarding the age of the infested structure was secured, and is given in the report of each case. Table 25 summarizes the information obtained. Cases of more special interest are discussed in greater detail following the table. Figure 81 illustrates characteristic locations of infestations, as indicated by these examinations.

TABLE 25

BUILDINGS INSPECTED FOR INFESTATIONS OF DRY-WOOD TERMITES

Case No.	Occupancy classification	Type of construction	Age of building in years	Nature of infestation
1	Railway station	One-story, wood frame	35–40	Many studs of west wall from near bottom of studs to roof
2	Apartment	Three-story stucco, wood frame	8–10	In studding, plate, and joists in south wall at floor level of second story
3	Cafe	One-story, wood frame	30–40	Joists, rafters, and sheathing in uppermost story of building generally infested
4	Residence	Two-story, wood frame	12–15	Rafters and sheathing in small area (about 6 sq. ft.). See discussion below
5	Residence	One-story, wood frame	15–20	Small area of wood siding
6	Residence	One-story, wood frame	12–15	General in flooring, which was replaced.
7	Residence	Two-story, wood frame	12–15	Small area of shakes at corner of porch, and extending into porch column; interior door casing between dining room and sitting room
8	School	Three-story, wood joisted brick	15–20	One rafter
9	Residence	One-story, wood frame	20–25	Very general. See detailed discussion below
10	Warehouse	One-story, wood frame	25–30	General infestation, studding rafters, joists, sheathing, siding, and flooring. See discussion below
11	Residence	Two-story, wood frame	12–15	Siding, studding, and flooring. See discussion below
12	Club house	One-story, wood frame	15–20	Studs, braces, brackets, and rafters. See discussion below
13	Residence	One-story, wood frame	10–12	Door sill and wood trim in vicinity (fig. 82). See discussion below
14	Residence	See discussion below	31	Studding of floor and all walls of sleeping porch (fig. 83). See discussion below
15	Business block	Three-story, wood joisted concrete block walls	30–35	Joists and flooring in portion of third floor
16	Residence	One-story, wood frame on wood post foundation	15–20	Foundation posts
17	Ruins	Adobe walls	100 (?)	Hewn window frame
18	Undertaking establishment	See discussion below	15–20	See discussion below
19	Barn	Two-story, wood frame	25–30	Siding, joists, studs, and rafters
20	Residence	Two-story, wood frame	20–25	Studs, sill, plate
21	Fruit packing plant	See details below	16	See details below

Case 4.—This was a two-story frame dwelling in Watsonville, California, 12 to 15 years old, in which two separate infestations were found, each apparently a single colony. One infestation was in the roof on the south side of the building, where parts of four rafters midway between the eaves and the ridgepole, and the sheathing above the infested rafters, contained passages of the common dry-wood termite. Altogether the infested area represented about 6 square feet. Thus far no serious injury had been done to the infested members, and the infestation was estimated to date back only 4 or 5 years.

The other infestation found in this building was also in the roof, where it occupied an area of about one square foot in a section of a rafter and in the sheathing and the shingles above it at the eaves. This infestation appeared to be even more recent than the other. The original colonizing pairs apparently entered the roof between the shingles and the sheathing.

Case 9.—This was a one-story frame residence in Watsonville, California. It was inspected in June 1929, when it was from 20 to 25 years old. It was about 45 feet long × 30 feet wide, and proved to be thoroughly infested. In fact, the infestation was so general that it appeared inadvisable to renovate; razing the building seemed to be the more economical step in the long run. Inspection of the roof and attic disclosed sheathing, shingles, and rafters riddled with passageways. The joists and the flooring of the attic were infested, as were also the walls of the south side and east end of the building, where termite pellets were continually dropping to the floor. This infestation probably dated back 15 or 16 years. It was not possible to determine the number of colonies involved, but it seems probable that there were several.

Case 10.—This was a frame warehouse at El Cajon, California, 120 feet long × 40 feet wide, belonging to the San Diego and Arizona Railway. It was inspected in July 1929, when it was about 25 to 30 years of age. The building was generally infested with the common dry-wood termite and was near collapse as a result. The injury had become so serious in the past that the posts supporting the roof had been replaced. Studding, rafters, sheathing, joists, siding, flooring, practically all members, were infested. It was probably the most serious instance of infestation of a building by *Kalotermes minor* ever observed. No attempt was made to determine the number of colonies concerned in the infestation, but certainly a considerable number of large colonies was present.

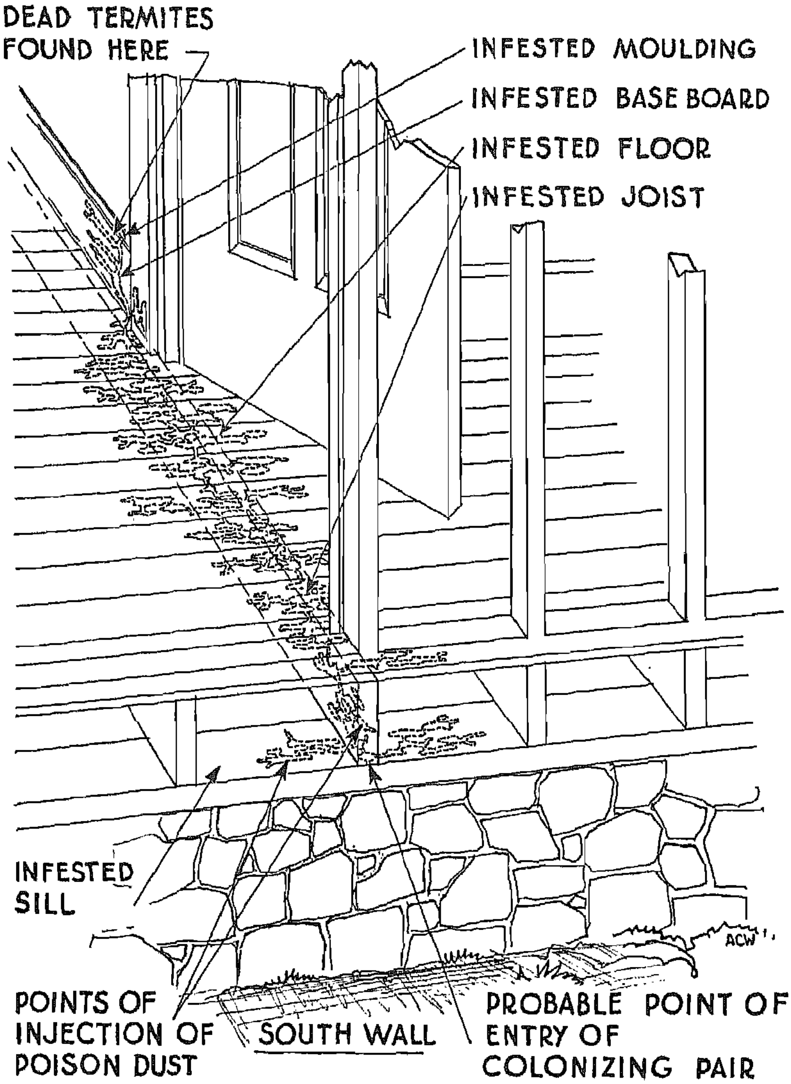
Case 11.—This was a two-story frame residence in Alhambra, California. It was inspected in September, 1929, at which time it was from 12 to 15 years old. An enclosed porch on the west side, removed since the inspection date, was infested in its siding, studding, and flooring. There were numerous termite passageways, although the infestation had not as yet seriously interfered with the utility of the affected parts. Apparently a single large thriving colony was involved.

Case 12.—This was the Woman's Club House at Covina, California. It was inspected in September, 1929, at which time it was from 15 to 20 years old. It was a frame building, the main part of which was about 120 feet long × 40 feet wide × 30 feet high, with a wing at the southeast corner. The walls of the main part of the structure were supported by brackets, and it was in the studs and braces of the brackets that the infestation was found, as well as in the plate and rafters. In fact, the infestation had become so serious in all of the members involved that fear was felt for the safety of the building. The danger was increased because of the structural nature of the framework. No effort was made to determine the number of colonies of termites involved, but there were probably several, since studs and braces on both the north and south sides were infested. The infested members were well riddled with passages. The infestation undoubtedly dated back several years, since the timbers forming the braces were 8-inch pieces consisting mainly of heartwood, in which the common dry-wood termite does not work so rapidly as in sapwood.

Case 13.—This building was a bungalow in Pasadena, California, inspected in October, 1929, when it was from 10 to 12 years old. A single infestation represented by a single colony of *Kalotermes minor* was discovered in the south wall (fig. 82). Apparently, a colonizing pair entered the sill through the crack between the sill and a joist, progressing thence into the floor, where the colony began to develop, and finally passed to the mopboard and the molding. It was decided to blow a poisonous powder into the termite passageways, through holes bored into a sill and joist (fig. 82), to determine the value of this method of treatment as a control measure. Later inspection showed termites killed by the poisonous powder in passageways in the molding near a closet door (fig. 82), which represented the limits of the infestation, indicating the effectiveness of the method.

Case 14.—This was a large, three-story residence in Santa Paula, California, inspected in October, 1929, when it was 31 years old. It was constructed of building blocks (fig. 83), with the exception of the laundry, which was frame at the time of this inspection. Since that time the laundry has been replaced with an addition of brick to the residence proper. The laundry was thoroughly infested with the common dry-wood termite. The studdings of all the walls, and the floor of the sleeping porch were riddled with passages. The situation was of particular interest because the infestation had progressed from the laundry into the southwest corner of the house proper, where the termites were becoming established in studding, plate, and rafters. Here they had done no appreciable damage thus far, but a foothold had been gained, and the roof and interior woodwork of the building were open to attack.

It is possible that the concrete building blocks protecting the frame of the building had deterred passage of the termites from the laundry to the main part of the structure. They almost certainly account for the fact that the main part was free from infestation by reproductives, while the laundry of the same age was heavily infested, probably with several colonies. The infestation in the laundry was estimated to be 20 years old, while the infestation in the southwest corner of the main part of the residence was probably but 4 or 5 years old, representing an extension of the activity of the termites after they had appreciably infested the laundry.



CASE NO. 13
SHOWING LOCATION AND EXTENT OF RUNWAYS
MADE IN BUILDING BY DRY-WOOD TERMITES.

Fig. 82.

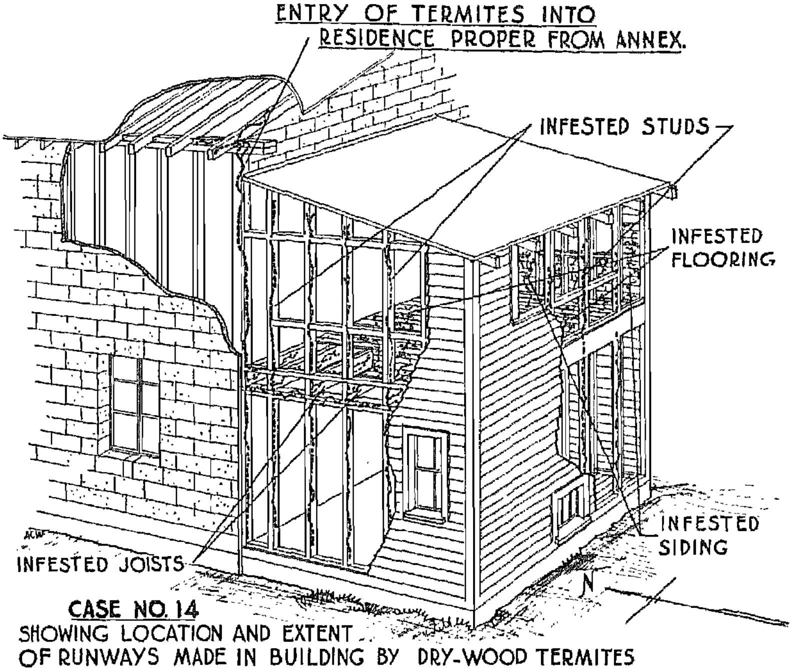

ENTRY OF TERMITES INTO RESIDENCE PROPER FROM ANNEX.
INFESTED STUDS
INFESTED FLOORING
INFESTED SIDING
INFESTED JOISTS
N
CASE NO. 14
SHOWING LOCATION AND EXTENT OF RUNWAYS MADE IN BUILDING BY DRY-WOOD TERMITES

Fig. 83.

Case 18.—This was a two-story business building in San Diego, California, used as an undertaking establishment. When inspected in July, 1930, it was from 15 to 20 years old. It was brick veneer for one-half of the first story, and stuccoed above. Seven infestations were found, all in the south wing, and three of them in a tile-covered half roof. The number of infestations, the extent of each, and the number of colonies in each, were determined without dismemberment, by tracing the course of the poisonous liquid injected under pressure to destroy the termites. The liquid passed through the termite galleries from member to member until all were filled and the liquid seeped out of the wood at the limit of the infestation. The separate infestations are discussed below.

(1) The center of infestation was in two jack rafters, in a hip rafter, and in 9 feet of sheathing on the inside wall in the northeast corner of the south wing, and in the roof sheathing close to the eaves, in which it extended for 12 feet. Apparently a single colony was involved.

(2) The center of this infestation was in the hip rafter and two jack rafters of the southeast corner of the south wing, and extended into one main rafter, the roof sheathing close to the eaves for 10 feet north of the corner, and for 28 feet west of the corner. Apparently a single colony was involved.

(3) An infestation by a single young colony was found in two studs on each side of the vent on the north wall, and in two courses of sheathing below the vent.

(4) The fourth infestation in the south wing of the building, also representing one colony, was situated in the casing and in the frame of a window screen 25 feet from the southwest corner on the second floor. It was a comparatively recent infestation, probably about 3 years old.

Three infestations, representing as many small colonies, were found on the ground floor of the south wing of the building, as follows:

(5) In the sheathing of the basement wall and top plate of the south wall, 25 feet from the southwest corner. This infestation was of about the same age, apparently, as the one in the window casing and screen.

(6) and (7) In the casings of two windows near the southeast corner of the south wing.

Case 19.—This was a barn in Palms, California. It was from 25 to 30 years old at the time of inspection, February, 1931. The barn, about 30 feet long × 24 feet wide, was a frame building with ground floor and loft. Some time previously an extensive infestation of the common dry-wood termite had been found. Advantage was taken of this opportunity to test the efficacy of poisonous dusts in the control of the dry-wood termites (chap. 38). The dust was injected through holes bored into the termite galleries. When opened at this inspection, some months after injection of the dust, the termites were found to be dead even in galleries remote from the point of application. This result not only proved the value of the treatment, but facilitated the determination of the extent of the infestation. Apparently more than one colony was involved, and the studs, siding, plate, sheathing, and rafters were thoroughly riddled. The infestation probably dated back almost to the time the barn was built.

Case 21.—This was a large packing plant in Santa Paula, California, 16 years old at the time of inspection, May, 1931. It consisted of three units, of which the middle one, the oldest, dated back to 1915. Five infestations were inspected, and two others reported. The middle unit had a "saw-tooth" roof over most of it, and was mainly frame construction. Six of the seven infestations were situated in it. The east unit of the plant was constructed of tile, although the walls of the storage rooms, of the sweat rooms, and of the packing rooms were frame. In this unit two infestations were found. The west unit of the plant was constructed of steel and concrete. The infestations inspected were as follows:

(1) An area of about 12 square feet on the south side, including a section of a girder, part of a double wall insulated with hair, parts of two joists of an upstairs packing room floor, and parts of the rafters of a storage shed. Apparently, this infestation was caused by a single colony. An interesting feature of it was the occurrence of termites in the insulation of the double wall. The colony was estimated to be at least 6 years old.

(2) A section of the skylight in the upstairs packing room, including the plate and portions of several adjoining studs, was thoroughly riddled with passageways, apparently the work of a single colony. This infestation probably dated back at least 6 years.

(3) In the northwest corner of one of the "saw-tooth" sections two studs, a section of the plate, and part of the framework of three windows were infested, and the passageways extensively penetrated each member. This was apparently the work of a single colony somewhat younger than the two reported above.

(4) On the north wall toward the east end of the "saw-tooth" section a purlin, six studs, the sheathing, and part of the framework of three windows were infested. This infestation was extensive and evidently was caused by a single colony.

(5) In one sweat room of the east unit the framework of a vent in the ceiling and sections of adjoining members of the insulated ceiling contained extensive passageways.

INFESTATION OF WOODEN OIL DERRICKS BY DRY-WOOD TERMITES

From September 24, 1928 to April 14, 1931 twenty wooden oil derricks were inspected by a Committee field man for possible infestation by termites. The derricks were picked at random in the Brea, Montebello, and Santa Maria (California) fields of the Union Oil Company.

Twelve of the twenty derricks inspected contained infestations of *Kalotermes minor*; three contained infestations of the western subterranean termite, *Reticulitermes hesperus* (one coincident with *K. minor*); and one, of the damp-wood termite, *Zootermopsis angusticollis*. Five of the twenty derricks were without infestations of termites. The data for each inspection are given in Table 26.

TABLE 26

Case No.	Age of derrick, years	Infestation by	Nature of *Kalotermes* infestation
1	11	*Reticulitermes*	
2	11	*Kalotermes*	Single, extensive infestation in one leg member
3	19	*Kalotermes*	Same as in No. 2
4	19	*Kalotermes*	In crown block and in all portions of all four legs
5	19	*Kalotermes*	Infestation in crown block
6	19	None	
7	19	*Kalotermes*	Lower girt members extensively damaged
8	19	*Kalotermes* and *Reticulitermes*	In water table, one leg member, and one foundation member
9	10	*Kalotermes*	In platform and in foundation member
10	10	*Kalotermes*	Royal pair, without progeny, found in corner of derrick foundation sill; advanced damage found in another portion of foundation sill
11	6	None	
12	10	None	
13	8	None	
14	11	None	
15	....	*Kalotermes*	Minor damage
16	26	*Kalotermes*	Extensive damage in portion of one leg
17	26	*Kalotermes*	Extensive damage in portion of leg
18	10	*Zootermopsis*	
19	10	*Kalotermes*	Recent infestation in crown block
20	10	*Reticulitermes*	

INFESTATION OF BRIDGE TIMBERS BY DRY-WOOD TERMITES

During the period from September, 1928 to April, 1931 twenty-four bridges located in southern California were inspected for possible infestation by *Kalotermes minor*. Of these but three were found infested, and in no case was the damage serious, being confined to the sapwood. Timbers of a number of these bridges were infested with either the western subterranean termite, *Reticulitermes hesperus*, or with the desert subterranean termite, *Heterotermes aureus*, and one with the damp-wood termite, *Zootermopsis angusticollis*, but these will not be discussed here, since they represent an entirely different problem.

CHAPTER 22

THE SOUTHERN AND MOUNTAIN DRY-WOOD TERMITES, *KALOTERMES HUBBARDI* AND *KALOTERMES MARGINIPENNIS*

BY

S. F. LIGHT

THE SOUTHERN DRY-WOOD TERMITE

Description.—*Kalotermes hubbardi*, the southern dry-wood termite, is characterized by the yellow color, pale wings, and intermediate size of the alates (13 mm. with the wings), and the enormously elongated third segment of the antennae of the soldiers. The keys given on pages 206–207 serve to distinguish it from associated species.

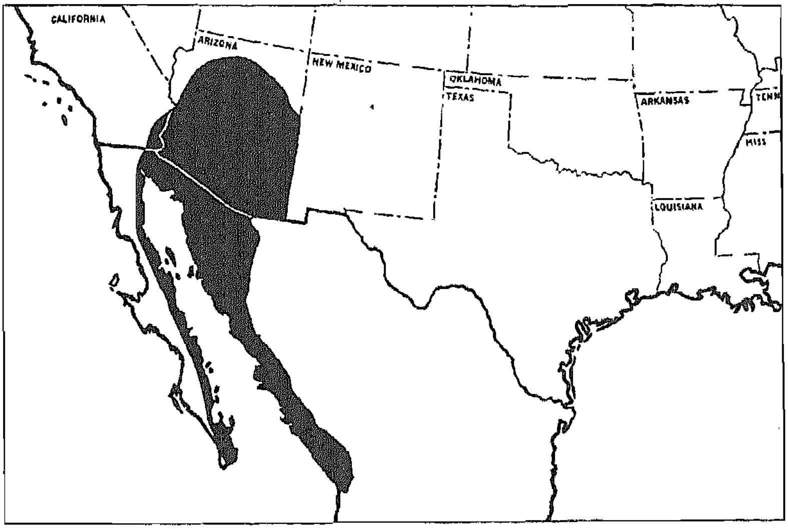


Fig. 84. Map showing the known range of *Kalotermes hubbardi*, the southern dry-wood termite.

Distribution.—The known range of the southern dry-wood termite extends, as the map (fig. 84) indicates, from the Colorado River Valley on the southeastern border of California through central and southern Arizona, to the tip of Lower California, and along the Pacific coast of Mexico at least as far south as the city of Colima (chap. 28), and to the islands off the coast of the mainland and of Lower California, including distant Socorro Island. How far inland its range extends is unknown, but it seems probable that it overlaps that of the mountain dry-wood termite, *Kalotermes marginipennis* (p. 259).

In Arizona it is found alone in the lower altitudes, as at Phoenix; at intermediate altitudes, such as at Tucson and Ray, it is found with *Kalotermes minor;* while at higher altitudes, such as at Prescott and Nogales, it is entirely replaced by *K. minor*. Similar conditions no doubt obtain in Sonora Province in Mexico. In Sinaloa, Tepic, and Colima provinces it is present with a number of other dry-wood termites, whose ranges are largely unknown. Its probable relation to *K. marginipennis* has been mentioned, and in Colima it shares the economic field with the common powder-post termite, *Cryptotermes brevis* (pp. 197–198, 307).

Economic significance.—In all this area *Kalotermes hubbardi* is the economically important dry-wood termite, being second only in general importance to *K. minor,* which it would no doubt far outstrip both in damage done and in difficulty of problem presented, did its range include either large population centers or regions where wood construction predominates. As it is, everywhere in the cities of the Pacific coast of Mexico where observations have been made (Guaymas, San Blas de Sinaloa, Mazatlan, Colima) its abandoned and exposed workings are conspicuous sights in the wood of shutters, doors, door and window frames and jambs, floor boards, furniture, etc.

Special biology.—*Kalotermes hubbardi* is a typical dry-wood termite with the same general habits of life, so far as known, as those described for *K. minor,* but with several outstanding differences. It is plainly adapted to higher temperatures, as indicated by its range. Further, both field observations and laboratory tests on moisture preference indicate that it not only thrives, but actually prefers, much drier conditions than those required by *K. minor.* This seems plainly indicated by its numerous and extensive workings observed in arid to semi-tropical and tropical localities in relatively thin, unprotected surface boards, in which the temperature must be very great at times and the moisture content very low. In these particulars it approaches the powder-post termites, which are often found colonizing ¼-inch boards.

Like several of the powder-post termites, such as *Cryptotermes brevis, K. hubbardi* seems to be a true "house termite," at least in the southern part of its range, where, although extremely common in wooden structures, it is extremely rare in natural wood. In the northern part of its range the most important natural reservoirs of the southern dry-wood termite are the giant cacti of the desert and the cottonwoods of the canyons and stream beds.

In contrast to the common dry-wood termite, *Kalotermes minor,* but in agreement with most other dry-wood termites, *K. marginipennis,* etc., the alates of *K. hubbardi* are night-fliers, as their slight pigmentation would suggest.

The Mountain Dry-Wood Termite

Kalotermes marginipennis Latreille, the mountain dry-wood termite, is confined to the tablelands of Mexico, being abundant at altitudes as high as that of Mexico City (7,500 feet), where its alates are known by the pleasing name of Palomitas de San Juan. It is readily distinguished from all other common dry-wood termites by the large size of the alates (about 19 mm. long with the wings), which are light in color, with pale wings, and by the presence of a distinct tubercle on the antero-lateral corner of the dorsal surface of the head of the soldier.

Very little is known of this species, in spite of the fact that it was the first American dry-wood termite to receive a name. A single alate was pressed by mistake with one of the plants collected by Baron von Humboldt in Mexico. Discovered by the botanist who studied the collection, it was studied and described by the famous French entomologist Latreille, the figure appearing in 1811 and the description in 1832. Banks (Banks and Snyder, 1920) incorrectly identified the much smaller common dry-wood termite of southeastern United States and Central America, *Kalotermes snyderi* Light (pp. 262, 308), as this species, and all economic references to *K. marginipennis* previous to 1932 refer to *K. snyderi.* Snyder (1922) described the alate and the soldier, respectively, of the true *K. marginipennis* from specimens in the U. S. National Museum under the name of *K. montanus* (alate) and *K. tuberculifrons* (soldier). Light collected it in Tepic and Guadalajara, and, upon the suggestion of Emerson, he was able to show (1933) that it was Latreille's species.

So far as known, its habits are similar to those of *K. hubbardi.* As its light color would indicate, it is a night-flier. The scanty available information points to its potential destructiveness both in buildings and in living plants. The few colonies reported were located as follows: in the sapwood of a pole at Tepic; in dead heartwood of a living hardwood tree near Tepic; in timbers of two houses and an office building in Guadalajara; in a cultivated cactus at La Venta near Guadalajara; and numerous incipient colonies in dead branches of living castor oil bean at La Venta, all in Mexico.

CHAPTER 23

THE DRY-WOOD TERMITES OF EASTERN AND SOUTHERN UNITED STATES

BY

THOMAS E. SNYDER

Damage by dry-wood termites to buildings and their contents, and to telephone, telegraph and electric light poles, to bridges, fences, etc., is comparatively slight in the United States, except in a few regions in the Southeast and Southwest (fig. 59*b*). No damage to railroad ties in the road bed or to mine props in the mine has been discovered.

In eastern United States large public and other buildings in Key West, Miami, Palm Beach, and Tampa, Florida; New Orleans, Louisiana; Savannah, Georgia; Charleston, South Carolina, and, less commonly, elsewhere, have been more or less severely damaged by dry-wood termites. Similar damage to furniture has also been observed in these and other cities.

Damage to untreated poles, both to the bases and to the tops, by dry-wood termites has been observed in Florida, Georgia, South Carolina, Alabama, Mississippi, Louisiana, and Texas (see also chapters 19–22).

A list of the species of the dry-wood or non-subterranean termites of eastern and southern United States, with their distributions in the United States, follows. A brief discussion is given of certain of those whose biology and economic significance are known.

Kalotermes (Kalotermes) approximatus Snyder, Florida, Louisiana, Virginia.

Kalotermes (Kalotermes) jouteli Banks, Florida.

Kalotermes (Kalotermes) schwarzi Banks, Florida.

Kalotermes (Kalotermes) snyderi Light (= *K. marginipennis* Banks and Snyder), South Carolina, Georgia, Florida, Louisiana, Texas.

Kalotermes (Kalotermes) texanus Banks, Texas.

Kalotermes (Neotermes) angustoculus Snyder, Florida.

Kalotermes (Neotermes) castaneus Burmeister, Florida.

Paraneotermes simplicicornis Banks, Texas.

Cryptotermes brevis Walker, Florida, Louisiana.

Cryptotermes cavifrons Banks, Florida.

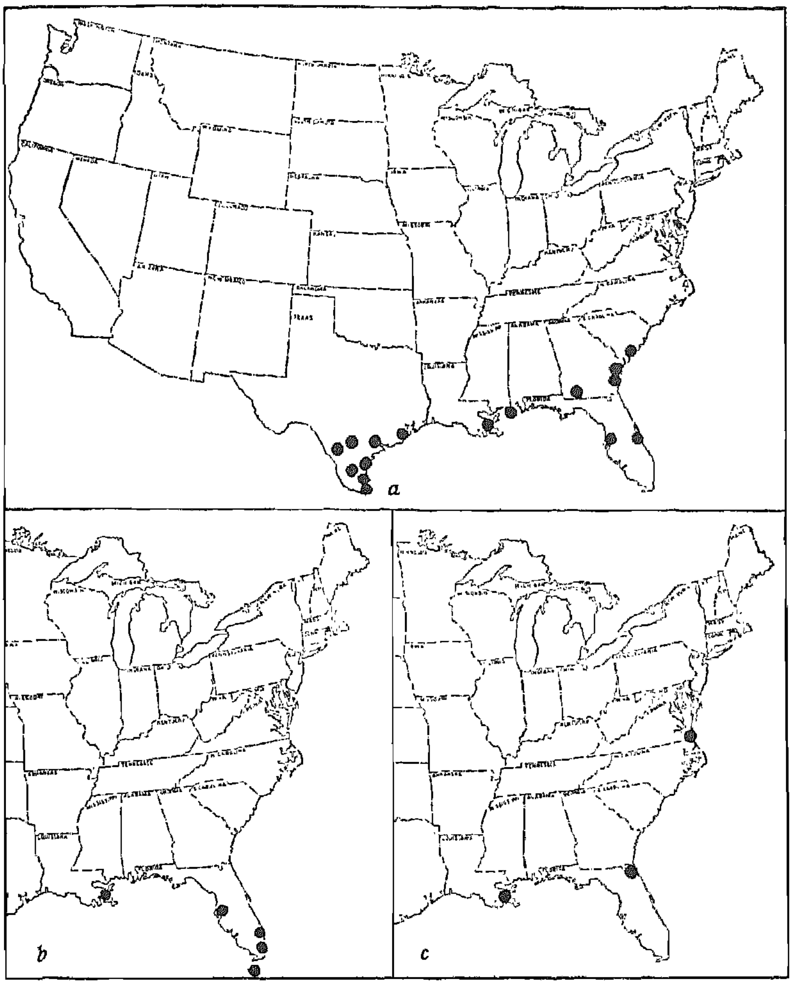


Fig. 85. Maps showing by black dots the known distribution of dry-wood termites in eastern and southern United States. *a. Kalotermes snyderi* (=*K. marginipennis*). *b. Cryptotermes brevis. c. K. approximatus.*

Kalotermes approximatus Snyder

This termite, the only dark-colored eastern species, has as yet been found only in northern Florida, in New Orleans, and in southern Virginia (fig. 85*c*). It has been found in dead trees, logs, and stumps, as well as in the woodwork of buildings.

Swarming.—Winged adults of this termite were found at Cape Henry, Virginia, in the vicinity of the sand dunes, in a dead bald cypress tree, on August 23, 1924. They had attained their mature pigmentation.

Kalotermes jouteli Banks

This species is not common in the United States, being restricted to southern Florida, including the Keys, but also occurs in Cuba and the Bahamas, in the West Indies, and in Mexico. This termite has seldom been found to be injurious except in a few cases in the moist foundation timbers of buildings. In nature it lives in dead trees and in logs and branches lying on the ground.

Swarming.—The colonizing flight of this termite occurs in late autumn. Young dealated macropterous queens, and brachypterous and apterous reproductive forms have been found in colonies, none more than slightly physogastric.

Kalotermes schwarzi Banks

This is one of the commonest termites of the genus *Kalotermes* in southern Florida; Pensacola is the northern limit. This species also occurs in Cuba, Jamaica, and the Bahamas in the West Indies, and in Yucatan, Mexico. It attacks both the woodwork of buildings and the bases and tops of telegraph and telephone poles, including cross arms and insulating pegs. In nature it is found in dead trees, logs, and stumps.

Swarming.—The colonizing flight occurs late in April or in May. Both macropterous and brachypterous reproductive forms have been found in colonies, but the queens were only slightly physogastric.

Kalotermes snyderi Light

This termite is the most widely spread (fig. 85*a*) and injurious of the eastern species of dry-wood termites occurring in the United States. It damages not only the woodwork of buildings, but also both the bases and tops of telegraph and telephone poles. In nature it is found in dead trees, logs, and branches. Several termites in Central America and Hawaii have been confused under the name *Kalotermes marginipennis*. *K. snyderi* was considered by Banks and Snyder to be *K. marginipennis* Latreille.

Swarming.—This termite swarms at night, as do most other species of this genus. The swarm is usually in May and June, and the winged adults are attracted to lights during flight. Young macropterous reproductive forms of this species have been found in colonies.

Kalotermes (Neotermes) castaneus Burmeister

Several species in South and Middle America, North America, and Hawaii have been confused under the name *castaneus*. In the United States it occurs only in southern Florida, including the Keys; this species is also found in the West Indies, Middle and South America. As yet this species has not been found to be injurious to the structures of man, but in addition to living in the dead wood of trees, logs, stumps, and branches, it attacks and damages living fruit trees.

Swarming.—The colonizing flight occurs the last of May and the first of June. Both macropterous and apterous reproductive forms have been found in colonies; the queens were only slightly physogastric.

Kalotermes (Neotermes) angustoculus Snyder

This termite apparently has the same distribution and habits as *K. (N.) castaneus,* under which name it was formerly included.

Cryptotermes brevis Walker

Cryptotermes brevis, the common powder-post termite, is of wide distribution in the West Indies, Mexico, Central America, and South America, but in the United States is found only in southern Florida and New Orleans, Louisiana (fig. 85*b*). It is *never* found in nature living in logs, etc., but is entirely a house termite, damaging the woodwork of buildings and furniture. It has been known to destroy the woodwork and furniture in large hotels in the West Indies and in southern Florida. Moreover, it not only destroys floors, furniture, etc., but the constant dropping of pellets from infested wood is an annoyance to the householder. Its destructive habits in Middle and South America have given it a special native name, "carcoma," in contrast to that given the subterranean termites, "comejen" (see also chapters 19 and 28).

Swarming.—In the United States the colonizing flight occurs in May or June. Slightly physogastric macropterous reproductive forms have been found in colonies.

Cryptotermes cavifrons Banks

This species occurs in the West Indies and southern Florida. It is apparently, at least as yet, not a species of economic importance, being found only in nature in dead trees, logs, stumps, and branches.

Swarming.—The colonizing flight occurs in April or May. Macropterous, physogastric reproductive forms of relatively large size have frequently been found. Eggs are deposited in small separate pockets amidst fluffy wood fiber frass, a habit apparently peculier to this species.

CHAPTER 24

THE DAMP-WOOD TERMITES OF WESTERN UNITED STATES, GENUS *ZOOTERMOPSIS* (FORMERLY, *TERMOPSIS*)

BY

GORDON B. CASTLE

The damp-wood termites include a group of species of wood-dwelling termites which require much moisture and locate their colonies, in part at least, in damp and hence often decaying wood. This small but heterogeneous group includes species belonging to three distinct genera, *Zootermopsis, Paraneotermes*, and *Prorhinotermes.*

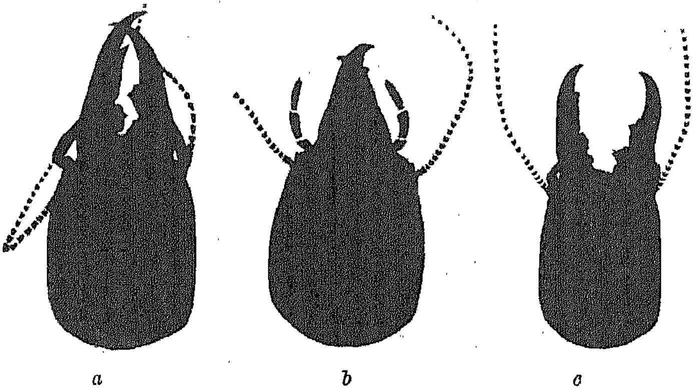


Fig. 86. Heads of the soldiers of the three species of the genus *Zootermopsis* Emerson, (1933). × 7. *a. Z. laticeps,* the Arizona damp-wood termite. *b. Z. angusticollis,* the common damp-wood termite. *c. Z. nevadensis,* the small damp-wood termite.

Zootermopsis (= *Termopsis*) is a remarkable genus confined to western North America. It includes three species (fig. 86), *Z. angusticollis* Hagen, the common damp-wood termite, *Z. nevadensis* Hagen, the small damp-wood termite, and *Z. laticeps* Banks, the Arizona damp-wood termite. *Z. angusticollis* has been chosen as the type for this group since it is better known than either of the other two species. The information given below for *Z. angusticollis* will apply to *Z. nevadensis* except in certain instances, which will be treated separately. *Z. laticeps* is very rare and little is known of its life history or biology.

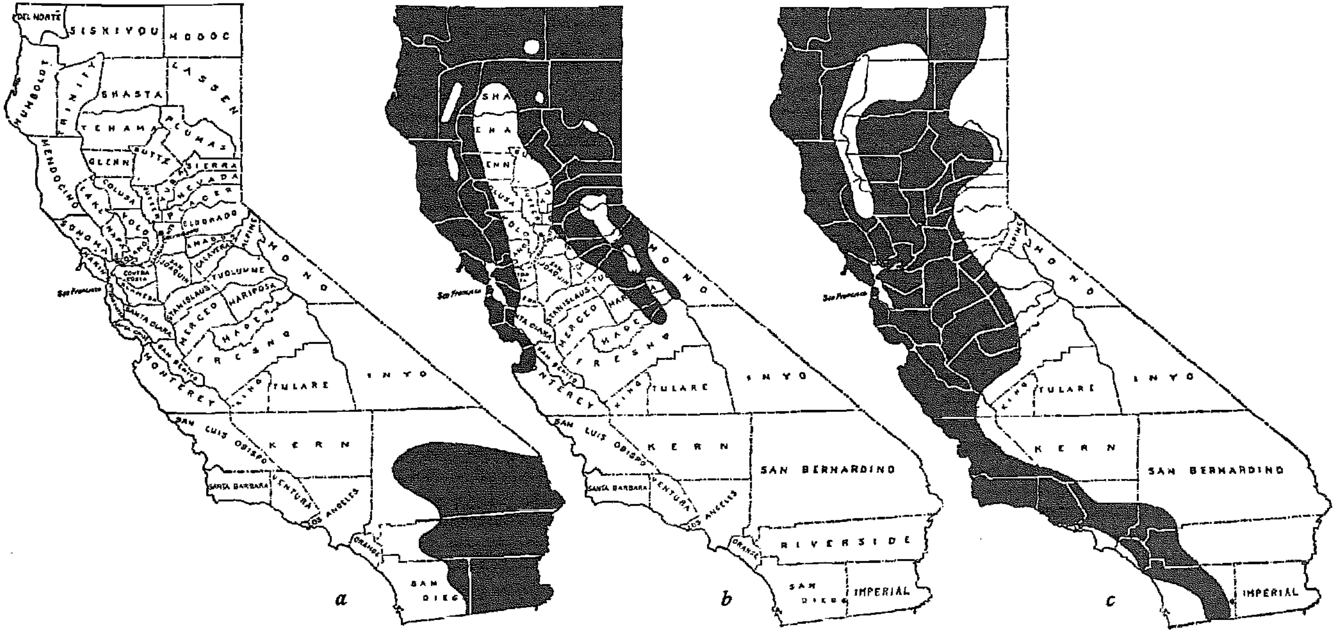


Fig. 87. Maps showing in black the distribution in California of, *a*, *Paraneotermes simplicicornis*, the desert damp-wood termite; *b*, *Zootermopsis nevadensis*, the small damp-wood termite; and *c*, *Z. angusticollis*, the common damp-wood termite.

Zootermopsis angusticollis, the common damp-wood termite, has the most northerly distribution of any of the wood-dwelling termites of North America and probably extends farther south than any other damp-wood termite. Its known range extends from Victoria, British Columbia, at least as far south as the Mexican border, and it probably occurs south to the San Pedro Martir Mountains in Lower California and to Santa Morganta and Guadalupe Islands. In the northern portion of its territory it has an altitudinal range extending from sea level to 4,000 feet; in its southern extension it is found as high as 6,000 feet. It is the common damp-wood termite in the more humid coastal areas (fig. 87*c*).

Zootermopsis nevadensis, the small damp-wood termite, is found from Vancouver Island, British Columbia, south at least to central California, and from the Pacific Coast east to Montana. It has an altitudinal range in the northern area extending well above 5,000 feet, and is the common damp-wood termite in cooler, drier, higher areas (fig. 87*b*).

Zootermopsis laticeps, the Arizona damp-wood termite, is the least known of the three species. Its known range limits it to the southeastern portion of Arizona and the southwestern portion of New Mexico.

Zootermopsis angusticollis (Hagen)

Description of castes.—*Zootermopsis angusticollis* is the largest of the Pacific Coast termites. It and its congeners are also the most primitive of the American termites, having a less highly evolved social system and many primitive morphological characters. Like other wood-dwelling termites, *Z. angusticollis* lacks the worker caste, which is a characteristic of the more highly developed termites. It has only two well defined castes, the *soldier* and the *reproductive*. The latter is subdivided into three different types. In every colony at least two castes, the soldier (fig. 89*d*) and one type of reproductive caste (fig. 89*a*), are found, and in some cases there may be as many as three, the soldier and two types of reproductives. Nymphal stages (figs. 89*b*–*c*, 90, 88), however, make up the greater percentage of the individuals in the colony, as brought out below.

The soldiers are the most interesting caste, due to their formidable appearance (fig. 89*d*) and pugnacity. They are variable in size, ranging from about ⅜ inch to ¾ inch or more in length. This variation in size depends upon the age and constitution of the colony and upon the instar in which the individual assumed its typical soldier characteristics, which seems to vary with the age of the colony. The head is large and is armed with a pair of long, black, toothed mandibles. The anterior portion is black, generally shading to a dark reddish-brown in the posterior portion. The thorax and abdomen are a light caramel color, the abdomen being slightly darker, due to the intestinal content.

The most common and perhaps the most important form of reproductive among the wood-dwelling termites is the first form. This is the form which, when it has completed its development, emerges from the last molt as a perfect insect with completely developed sex organs, wings, and compound eyes (figs. 3*a*, 89*a*, 90*a*). The body of the winged form is light cinnamon-brown. The wings are from 7/8 inch to 1 inch or more in length, dark brown, heavily veined, and leathery in appearance. The head is flattened and almost round in dorsal view, and bears a pair of large, black, compound eyes. The wings are shed after the swarm, and the first forms found in colonies have only short wing stubs on the thorax (fig. 90*c*), which give evidence of the previous possession of wings. A year or more after swarming the female's abdomen becomes somewhat swollen, white bands showing between the brown abdominal segments.

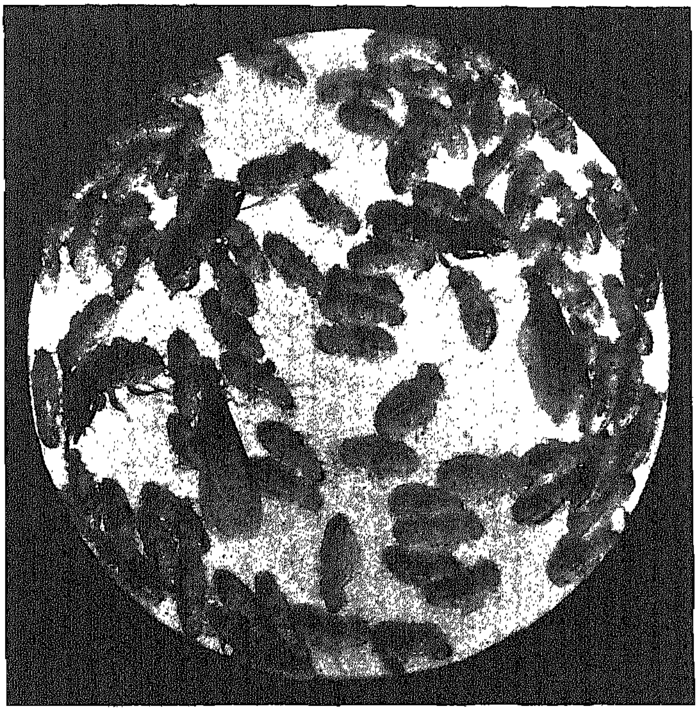


Fig. 88. Photograph of a group of individuals from a colony of the common damp-wood termite, *Zootermopsis angusticollis*. Natural size. Note the numerous nymphs, three soldiers, and two winged reproductives, or alates, ready for swarming.

The remaining types of reproductives are classed as supplementary forms. They appear in colonies that have lost either one or both of the primary reproductives, or in groups that have been isolated from the parent colony. These substitute forms are of two types: (1) the second form, or brachypterous, reproductives, and (2) the third form, or apterous, reproductives.

The second form is rarely found. It is one which has developed from a nymph of the first form or from an individual that is similar to a first form nymph. In typical individuals it is a light caramel color, the abdomen is

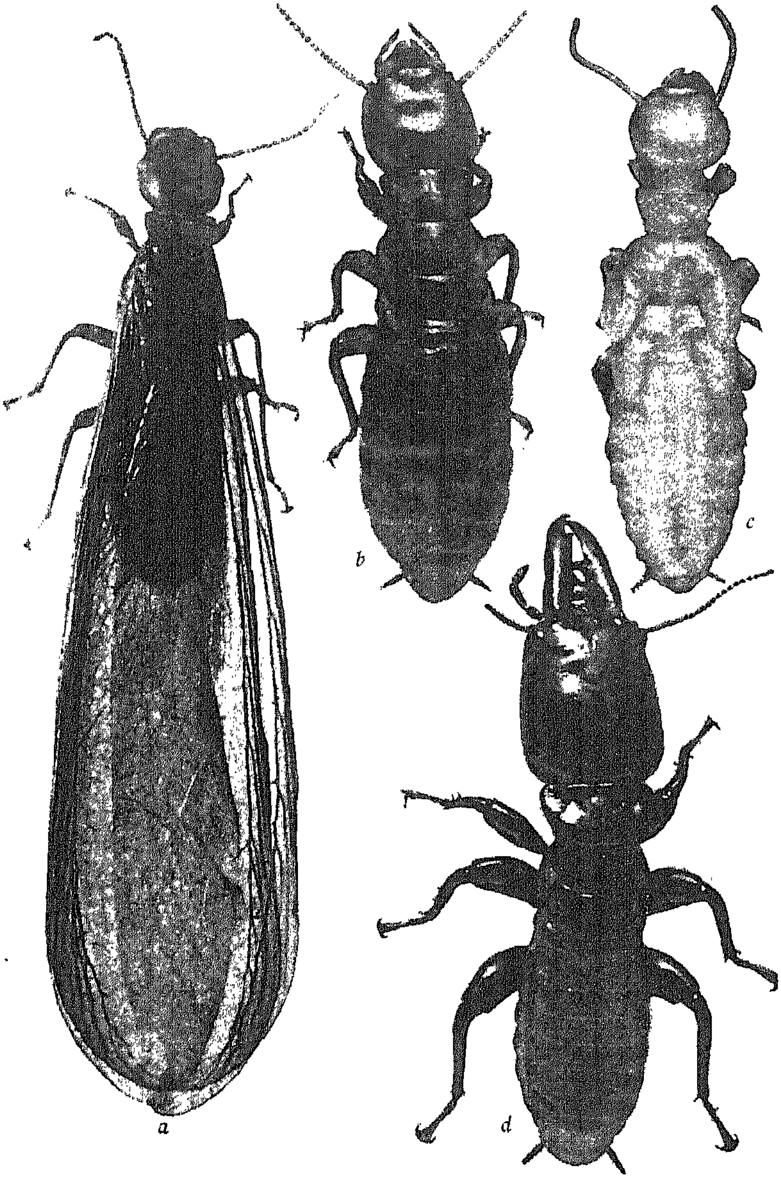


Fig. 89. Castes found in a colony of the common damp-wood termite, *Zootermopsis angusticollis*. × 5. *a*. Winged reproductive, or alate. *b*. Nymph which will become a soldier at its next molt. *c*. Nymph with wing pads, which will molt once to become an alate. *d*. Soldier. From *Calif. Agr. Exp. Stn. Circ. 318, fig. 1.*

slightly darker than the rest of the body, due to the intestinal content, the eyes are well developed but smaller than in the first form, and are pigmented, and the thorax bears short, flat wing pads. In some cases these wing pads are either lost or mutilated, the short wings being visible.

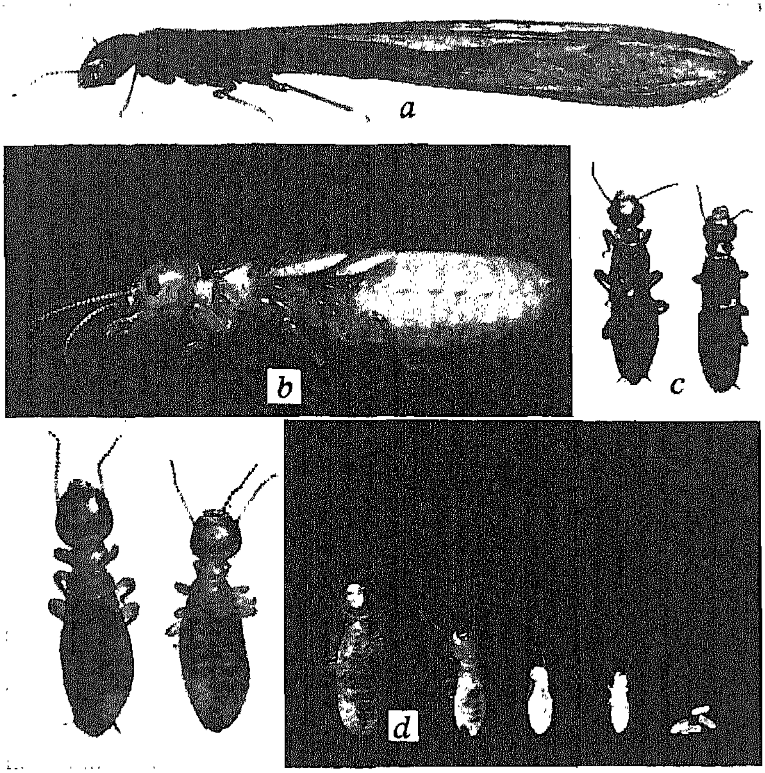


Fig. 90. Reproductives of *Zootermopsis angusticollis* and stages in their development. *a.* Winged individual seen in side view. × 3.5. *b.* Late seventh instar nymph photographed in side view, showing the swollen wing pads and pigmented compound eye. × 4.5. *c.* A royal pair, male at right. × 2. *d.* A series of developmental stages. Reading from right to left, they are eggs, and first, second, third, fourth, fifth, and sixth instar nymphs. The nymphs were photographed at somewhat higher magnification (×3) than the eggs (×2).

The third form reproductives are found more frequently than the second form. They are developed from soldier nymphs or from individuals that are very similar to soldier nymphs. They have the same coloration as the second form, the eyes are rudimentary, unpigmented and very small, and the thorax does not bear wing pads, or stubs.

In addition to these definite adult castes, the colony also includes as the great majority of its individuals the nymphs of these castes in various stages of development (fig. 90*b, d*). These young are white or slightly cream colored; the abdomens of the older nymphs are discolored due to the intestinal contents. These nymphs vary in size from those which have just hatched and are about 1/8 inch long, to the older forms, which are almost ready to metamorphose into one of the adult castes, and which are about 1/2 inch or more in length (figs. 90*b*, 88).

Size, location, and constitution of colonies.—Colonies of *Zootermopsis angusticollis* occur in down wood, stumps and stubs along streams, in the foothills, valleys, and canyons of California, Washington, and Oregon. Pine and

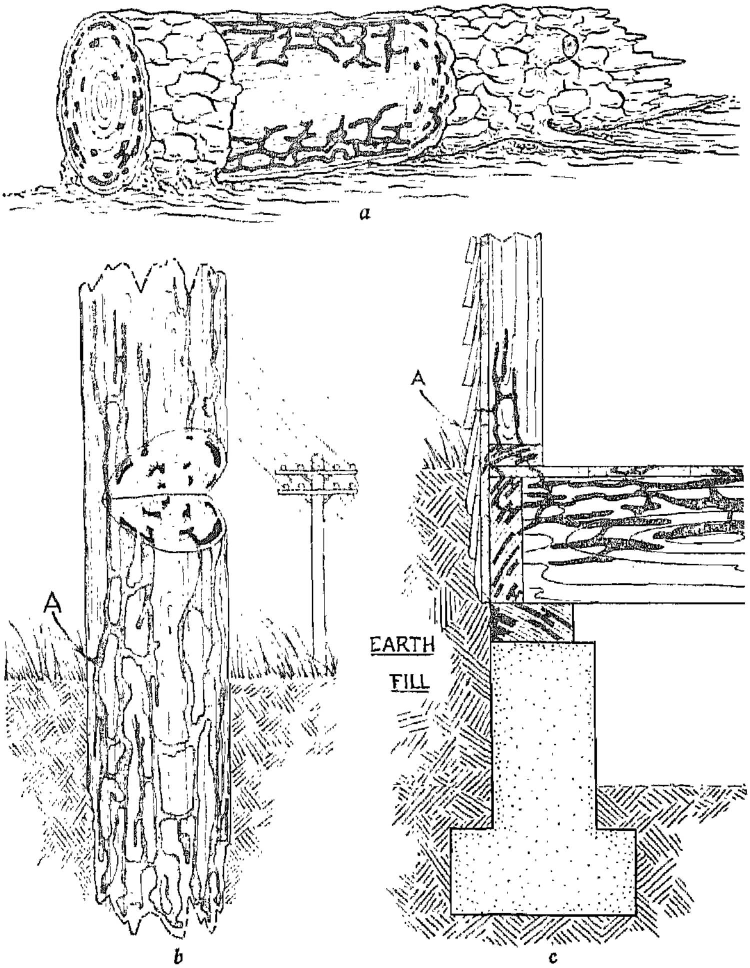


Fig. 91. Workings of *Zootermopsis angusticollis*, the common damp-wood termite, schematically represented. *a*. Sketch showing the galleries of a colony of *Z. angusticollis* in a pine log. *b*. Sketch showing the subsurface galleries of *Zootermopsis* in a pole, and the location of the deeper galleries. *A* marks the supposed point of entry of the colonizing pair which founded the colony. *c*. Sketch to illustrate the nature and location of runways of *Zootermopsis* in a building, and the common cause of such infestations, earth banked against the wooden structures furnishing the moisture requisite to their development. *A* marks the supposed point of entry of the colonizing pair which founded the colony.

fir logs, either rotten or in the first stages of decay, are usually attacked (fig. 91*a*). In areas where redwood is prevalent, dead wood of this species is also attacked, sometimes in dead parts of standing living trees, the sapwood being preferred. The wood attacked is so situated as to insure a plentiful supply of moisture. The colonies are commonly found in wood buried in, or lying on, the ground, and the termites are usually found very close to earth, although cases are known where their work extended as high as ten feet in poles. Although this species is capable of building runways through earth, as has been shown by laboratory experiments, such runways have never been encountered in the field.

Zootermopsis angusticollis occasionally attacks man-made structures, these attacks being more common in the cooler portions of its range. In houses the infestation is usually in the extremely damp, decayed parts, with occasional burrows leading into sounder wood (fig. 91*c*). Any wood in or on the ground that is moist throughout the year is highly susceptible to attack. Poles, piling, bridge timbers, and other structures built over or near water are also subject to attack.

Old colonies, whether located in down timber in the forests or in wooden structures in the city, serve as reservoirs from which a large number of flying reproductive forms emerge each year and infest wood in the vicinity. Such reservoirs should be destroyed or removed in order to reduce the possibility of infestation to a minimum, but it is even more important to eliminate the source of moisture or remove the wood therefrom, thus avoiding loss from fungus attack as well as termites.

Colonies vary greatly in population, reaching a maximum of at least four thousand individuals. The size of the colony seems to depend on (1) its age, (2) the time of year examined, and (3) the existing ecologic conditions.

The axiom "the older the colony the greater the size" holds true for *Zootermopsis angusticollis* if ecologic conditions are favorable. New colonies of this species, if opened a few months after the swarm, will contain the royal pair, several eggs, and perhaps one or two nymphs. A colony one year old will have, on the average, the royal pair, one soldier, and from twelve to twenty nymphs. Colonies several years of age, still headed by the first form pair, have been known to contain thirty-five hundred individuals (Heath, 1927). Larger colonies headed by the primary pairs are seldom found. This is probably due to the fact that the area necessary for the housing of such a group is so extensive that parts of it become isolated from the main group. These isolated groups produce reproductives of the supplementary type and develop separate organizations which are units in themselves.

If the same colony is opened at different times of the year it will be found to contain a different population at each examination. During the winter, spring, and early summer young are being produced and the population is steadily increasing. During the late summer and early fall older nymphs are continually metamorphosing into perfect insects. This metamorphosis is followed by the autumnal swarm which depletes the population of the colony.

The third group of factors, ecologic conditions, have much influence on the size of the colony. Very low or very high temperature and moisture conditions have disastrous effects on colony population. Very high temperature and low moisture supply cause the death of many colonies by dessication. Excess moisture may subject the colony to attack by certain fungi which it has difficulty in controlling. Changing ecologic conditions also account for diminution of numbers. After long, dry seasons colonies are found which have dwindled to a small portion of their original size, being reduced to last instar nymphs.

On opening a colony of *Zootermopsis angusticollis* the members of the colony, chiefly nymphs, are seen in the runways. Being negative to light, they immediately run about in an excited manner, searching for an entrance by which to retreat into the darker portion of their burrows. On careful examination, the tunnels will be found to be part of an extensive interconnecting series (fig. 91*a*). If the wood is comparatively sound, the tunnels will follow the annual rings, the soft spring wood being eaten; if, however, the wood is considerably decayed, they will pass through both the spring wood and summer wood. The tunnels vary in size and shape; some are oval in section, others round, some are long and broad. The smaller ones have a long diameter of two or three inches and a short diameter of one-half inch or more. The surface of the runways has a velvety appearance and sometimes is covered with dried liquid feces.

Throughout the colony are seen the fecal deposits of the termites, called pellets. These are small, hard, oval objects, about 1 mm. long (fig. 68*a*), and are colored according to the kind of wood the termites are using for food. The pellets are slightly hexagonal, due to the fact that the material is compressed in the rectum before it is voided. If the termites live in an extremely damp piece of wood the pellets are often round or without shape, because of the moistness of the food. In such moist burrows the pellets are deposited at random and usually stick to the sides of the runways. In drier wood the pellets are dropped and collect at the bottom of various chambers, or are sometimes carried to openings at the outside and thrust out.

Occasionally, when examining a colony, certain burrows will be found to be shut off from the remainder of the colony by dams built of pellets stuck together with either liquid feces or salivary secretion. The dams are used to isolate the colony from old, abandoned runways, other termites, fungus, and ants or other insect enemies.

As stated above, the castes of any one colony vary with the time of year and the age of the colony. A colony one year old will contain the royal pair, one soldier, and from twelve to twenty nymphs. This soldier-nymph ratio is gradually decreased as the colony becomes older, averaging about one soldier to fifty or more nymphs after four or five years. Throughout the greater part of the year only adult reproductives, soldiers, and nymphs are present. Just preceding the swarm the alates (figs. 98*a*, 90*a*) make their appearance and are found in the colony in large numbers until the swarm takes place. Immediately following the swarm a noticeable increase in the relative number of soldiers is found. Several colonies opened after swarming had occurred were found to contain many soldiers that had just molted from the nymphal form. This molt seems to be linked with the swarm in that all the potential soldiers and alates of the same age appear to change to their adult form at the same time. This increase in soldiers further disturbs the balance of the soldier-nymph ratio, but it has been noted that only the larger soldiers are retained, the smaller ones being killed off. One colony kept under observation in the laboratory for several months showed this peculiarity. When first established, one soldier of the sixth instar was present. Later, two more soldiers were produced, each succeeding one larger than the former. As soon as the newly molted soldier had become partially chitinized, the older soldier was dispatched by the nymphs.

In colonies headed by supplementary reproductives the number of kings and queens varies. In one colony of about two thousand individuals as many as twenty-six supplementary reproductive forms were found. These undoubtedly serve an important function in allowing for rapid increase in numbers and wide distribution of the colony through the log which they ordinarily inhabit.

Swarming and pairing.—At some time during the year winged forms are produced which fly away to establish new colonies. These yearly flights are called swarms. These reproductive forms have been taken flying during every month of the year, although the majority of such swarms occur during August, September, and October. On warm, sultry, quiet evenings these winged forms emerge and start on their search for mates and new homes.

Preceding the swarm, long slit-like openings are made to the outside of the wood in which the colony lives and the rims of the opening lined with either liquid feces or pellets. After the aperture is completed, supposedly by nymphs, one or two soldiers stand directly within the opening, their mandibles thrust out, lying in wait for any intruder. About dusk, from five until eight o'clock, the winged forms emerge. They crowd past the soldiers and crawl rapidly through the opening in two's, three's, or four's. Arriving outside they immediately orient themselves toward a region of higher light intensity, crawl in that direction for two or three feet, and then take wing. The wing beat is slow, heavy and labored, but powerful. One individual was followed during a flight of about 350 yards before it came to rest. They are doubtless able to fly great distances in search of colony sites. Individual alates have been noted on numerous occasions to make a series of successive flights, investigating numerous surfaces before choosing one to enter. The maximum height of flight is not known, but alates have been seen at least 50 feet in the air, and the infestation of a water tank on a seven-story building shows that they rise much higher. From all indications their ultimate destination is determined by at least two factors controlling their behavior, namely, their positive reaction to light, and their ability to locate decaying wood by its odor. Since these two factors often interact, it is difficult to determine accurately which is the more important. No doubt wind is also at times an important controlling factor.

Mating and founding of the colony.—Eventually several individuals of both sexes are congregated on a piece of wood suitable for colonizing, and the selection of mates begins. The first act is that of shedding the wings. This is accomplished by throwing one of the forewings forward, allowing it to drop and rest on the head. The termite then moves in circles, and, as the end of the wing projects in front of the head, it catches on débris or small pieces of wood, finally breaking off at the basal suture. The other wings are treated in like manner until all are shed. Following dealation, the termite runs about in an excited manner investigating holes, crevices, or any other sort of opening available. After several minutes of this random running about, the female stops, elevates the posterior portion of the abdomen, and awaits the arrival of a mate. Evidently an odor attractive to the male is given off which enables it to find the female. The male sets about at once grooming the female by means of the jointed feelers of the mouth parts, also using the mandibles. The female lowers her abdomen, allows the male to groom her for a few seconds, and then starts a search for a colony site. The male follows, but in contrast to male behavior in the mating of other species, he seems rather inattentive, often straying away from the female. If the male wanders too far from the female she stops, raises the tip of her abdomen again, and attracts either the wayward male or another. Having again obtained a mate, she continues the search for a home, and, on finding a suitable place, begins excavating. Most of the work falls to her lot, the male acting as a guard to prevent the intrusion of other males. The male occasionally goes into the opening to assist, but is more hindrance than help. When the opening is large enough to accommodate the pair, the male enters, and the opening to the outside is then closed with pellets and chips of wood cemented together with liquid feces.

During the next two or three days the cavity is enlarged. Within the first two weeks after the founding of the colony copulation takes place. This is accomplished by the male and female placing the tips of their abdomens together and remaining in that position from one to four minutes.

Colony Development.—From fourteen to eighteen days after the founding of the colony eggs are laid. These eggs (fig. 90*d*) are long, slender, and bean-shaped, about 1/16 inch long and less than half as wide when laid. They are white and translucent, without exterior markings. The first laying consists of from six to twenty-two eggs, the average being about twelve. The eggs are laid at the rate of one a day until four or five have been deposited. The rate is then decreased, one egg being laid every two or three days until the clutch is completed. No more eggs are laid until the next spring. The second lot of eggs laid in the spring is usually larger in number than the first, and the eggs are laid at the rate of one a day.

The rate of egg production varies with the type of queen and the age of the colony. In colonies several years of age, headed by the original first form queen, eggs are deposited during the greater part of the year, from six to eight months. During the remainder of the year the queen is in a resting stage, recuperating. Third form queens lay from thirty-five to forty eggs in a few days, after which there is a period of rest lasting from six weeks to two months.

The eggs are usually deposited in small side chambers not in use by the colony. In the case of the newly mated pairs these chambers are usually about an inch deep and just high enough to permit the entrance of one of the reproductives. During the incubation period the eggs are well taken care of. The first batch of eggs is cared for by the royal pair, but in the case of the later broods the work devolves on the nymphs. The eggs are moved about daily in the chamber, being taken between the mandibles and cleaned of any débris that may have collected on them. This moving about and changing allows for aeration; also, the eggs can thus be placed in that portion of the nest where the temperature and other conditions are optimum. Thus, if light falls directly on the eggs they are immediately moved to a dark place in the nest.

The incubation period was determined by noting the date of the appearance of the first egg and the subsequent appearance of the first nymph. It was found to vary from forty-four to eighty-eight days, with an average of fifty-six days.

Hatching of the eggs has been observed. A small opening appears at the anterior end of the egg. From this opening three splits arise, one extending down either side of the head, and a third down the mid-dorsal line. These slits gradually lengthen until the termite is able to pull its head free. It then slowly works itself out of the shell and wobbles away.

The newly hatched nymph is very small, about ⅛ inch in length, entirely white, with the exception of the tips of the mandibles and the spines of the legs, which are a light brown. It is very awkward during the first two hours after birth. However, it soon masters the six unruly legs and moves confidently about in the nest.

The termite remains in this stage for about ten days. During this time it receives stomodeal food from the adults or nymphs, and the body increases in size. After ten days it sheds its old skin and emerges as an individual of the second instar. The molting process is the same for all stages of development. A split occurs along the mid-dorsal line, extending from the posterior portion of the head along the thorax and the first few segments of the abdomen. The termite pulls its head down beneath its thorax and pushes itself through the opening in the old skin. The process takes several hours to complete, since not only all of the surface but also the lining of much of the alimentary tract, are shed. The newly molted individual has a larger head than before the molt. The body, however, although potentially larger, is in a shrunken condition. This is soon filled out by feeding.

The second instar lasts for twenty days, after which another molt occurs, the termite which emerges this time being larger, and now in the third instar. The nymph remains in this instar from twenty-two to twenty-four days, after which it may molt to another nymphal form, in which case it remains in the fourth instar for about forty-five days, after which it molts to the succeeding stage (fifth instar), or it may molt to a pseudo-soldier-nymph stage, that is, a form midway between the nymphal form and the soldier form. If it assumes the pseudo-soldier-nymph form, it remains as such for twenty days, after which it molts to the adult soldier form. During this pseudo-soldier-nymph stage, as in the case of the soldiers, wood-feeding is impossible, the individual being forced to feed upon stomodeal and proctodeal food and perhaps, in addition, small particles of débris or fecal material.

Further individual development has not been followed. From all indications the succeeding instars persist variable lengths of time, depending upon the age and constitution of the colony and the existing ecologic conditions.

Habits.—Knowledge of the habits of termites has been employed in controlling them. One habit, that of reciprocal grooming, is used as a means of distributing toxic powders throughout the termite colony.

Most termites, and *Zootermopsis angusticollis* is no exception, are very tidy, not only in respect to their burrows, but also in respect to their bodies. A termite can often be seen in the nest cleaning the antennae and occasionally the forelegs, using the palps and mandibles for that purpose. Reciprocal grooming, that is, grooming of one termite by another, is the most common means of cleaning. Grooming is done in the following manner: the groomed individual stands quietly while the groomer carefully cleans the legs, thorax, and abdomen. The mandibles and palps are used in the process. Most attention is given to the white areas between the abdominal segments. The termite being groomed assists in the process by turning the body and flexing its abdomen so that the groomer has better access to the covered portions. At times the termite turns on its sides so that the lower portion of the body can be groomed.

This habit has been used to great advantage in controlling colonies of termites in portions of wooden structures. Finely ground powder having toxic properties is blown into the runways. This powder adheres to the bodies of the termites and is later cleaned off by other members of the colony. In this way the powder is distributed through the group and kills its members (chap. 38).

Cannibalism is another habit which may also work to the same end. Occasionally, during the grooming process the groomer accidentally bites off a leg, antenna, or a portion of the body. Immediately a drop of the body fluid collects at the point of injury and the termite tastes it. This taste of body fluid sometimes excites the groomer to cannibalism and the groomed individual is partially eaten. At other times weak, diseased, or dead termites are eaten. The usual point of attack in killing a termite is the region of the first two abdominal segments. In many instances only a portion of the first two segments is eaten, the remainder of the animal being left to be destroyed by fungus, which is always present in the runways. If individuals weakened or killed by the toxic powder are eaten by the healthy individuals the poison may thus be spread further through the colony.

Requirements for Successful Growth of the Colony

In order for any animal or group of animals to live and reproduce, certain conditions are necessary. For the termites, as for other animals, the three most important factors required for colony growth are (1) a sufficient food supply, (2) a source of moisture such that it will supply the termites the necessary amount, and so located that it can be controlled, and (3) an optimum temperature, particularly during the egg-laying and incubation periods.

With respect to these various requirements, *Zootermopsis angusticollis* is adaptable. It is not limited to any particular condition of wood, although a preference is shown for rotten wood or wood in the first stages of decay. If such wood is not readily available, this species can burrow through sound wood, choosing the softer, spring wood. They are also well provided against the shortage of decaying wood in that they carry with them in their intestines spores of wood-destroying fungi. Fungus is found not only in the alimentary tract, but also on the body of the termite. If a swarming pair enter a decaying area in which the other conditions are favorable for their development, there is no reason to doubt the possibility that the colony to which they give rise will spread to the most distant boundaries of their burrows both the existing fungus and the fungus brought in on the bodies of the colonizing pair. In this way the fungus might precede them in their destruction, making available more desirable food for the growing and expanding colony.

Zootermopsis angusticollis must have a sufficient and controllable moisture supply. In nature this moisture is supplied by rains and by the absorption, by wood, of water from the ground. In houses moisture is supplied in many ways. If wood is in contact with the ground, moisture is supplied by capillary absorption. If, however, the wood is in an exceedingly dry place or above ground, the moisture can be supplied by many artificial means. Among these are leaking water pipes or drains, refrigerator drains, water storage tanks, and similar conveyors of moisture. In addition, moisture is sometimes supplied by washing or scrubbing portions of the house, or by artificial watering of gardens or flower beds. These sources are all sufficient and are for the most part controllable by the insect. *Z. angusticollis* is unusual in being able to adapt itself to exceedingly high moisture conditions. One infestation, in particular, has been investigated in which the wood was saturated with water.

The third requirement, temperature, is very important. Within certain limits termites are capable of controlling this factor within their burrows. This is accomplished by locating the burrows in wood in such a way that some will run below and some above ground. During extremely cold or extremely hot weather the termites migrate to the lower portion of their burrows to a region of more even temperature. *Zootermopsis angusticollis* does not show this particular characteristic so strongly as do other species of termites. However, there is less need for them to migrate, since they are able to withstand a wide range of temperature, as is shown by their distribution. A higher temperature is required during the incubation period and the early stages of development. Since eggs are laid in the spring and develop during the ensuing summer and fall, the temperature during that time is apparently ideal.

ECONOMIC SIGNIFICANCE

Due to the fact that the species of *Zootermopsis* are usually found in rotten or decaying wood, the tendency of early investigators has been to consider them of little economic importance. Consequently, the attention they have received has been largely of a biological nature, since they are ideal for laboratory study.

During the survey of the Termite Investigations Committee evidence was secured which indicates that *Zootermopsis* is of some economic importance. This evidence is rather limited, but points to the following conclusions:

1. The greatest damage done by these species is in shaded areas and areas where the moisture supply, either natural or artificial, is abundant.

2. They are most important in the northern portions of their ranges, *i.e.*, northern California, Washington, and Oregon.

3. While primarily inhabitants of decayed wood, such wood is not essential, since slightly weathered or sound wood can be utilized for food if sufficient moisture is available to the colony elsewhere; hence damage may extend from a moist pole butt up into the dry, sound wood above (fig. 91*b*).

Due to the fact that the investigations of the Committee were confined almost wholly to the State of California, and largely to central and southern California, no thorough survey of the regions most favorable to, and probably most affected by, *Zootermopsis* was made. However, a certain amount of evidence was secured from those regions. A few examples of their attacks on poles follow.

At Longview, Washington, several poles in a pole line about thirty miles in length which had been in service only five years, were badly damaged by *Zootermopsis angusticollis* and *Z. nevadensis.*

Concerning the attacks in Oregon, we quote one of our correspondents who is interested in the termite situation in that state. "We find termites in practically all pole lines of a few years service, and, although classified as *Zootermopsis angusticollis,* find them boring in sound wood more often than otherwise. During all my years spent in California I have not found the termite attack so general as it exists here."

The Southern Pacific Railway Company reported twenty butt-treated creosoted poles at Dunsmuir, California, attacked by *Zootermopsis.* The termites had entered the poles through seasoning checks and hollowed out the untreated wood in the interior portions of the poles adjacent to the treated area. These poles had been in service eleven years.

These few instances give an insight into the potentialities of this genus as an economic pest. They are isolated and selected cases, but doubtless an intensive survey in any part of their range would add greatly to them. It must be kept in mind that two factors operate to limit the number of such cases of damage by damp-wood termites. They are, first, the high moisture requirement of these termites, which limits the area in which they are to be expected, and, secondly, the fact that these conditions also favor deterioration from fungus attack, and therefore induce increasing resort to protective measures, chiefly treatment of the wood. At present there is every reason to believe that by proper treating methods the number of such attacks can be greatly reduced, if not entirely eliminated.

In regard to the last statement, it is necessary to cite two instances called to our attention in which treated poles were attacked. One of them has been cited above. Here the treatment was found to have been poorly done, leaving very thin shells at certain points.

The other case is quoted from a letter received from the correspondent in Oregon mentioned above. "The most interesting observation was termites found behind butt-treatment in butt-treated cedar poles. The butt-treatment was a good job, varying from one-half to one inch penetration." Here entrance must have been from above the line of treatment. It would be of interest to know the height of the treated portion above the ground line. Examples have been noted of incipient pairs entering poles above the ground level. In the regions around Auburn and in Mendocino County, California, such pairs have been taken two or more feet above ground in the base of poles. In time such attacks may be extended downward if the developing colony receives sufficient moisture to allow it to develop. Such conditions probably exist only occasionally.

In addition to the attacks on poles, there are numerous instances of attacks on board walks, curbing, bulkheads, fences, fence posts, etc., and in a few cases on buildings. In more than 90 per cent of these cases it was found that the wood attacked was in direct contact with moist ground, which furnished an ideal moisture supply. Floors, joists, sills, stringers, sheathing, and posts are included in the portions of the house attacked (figs. 91*c*, 92).

Figure 92 illustrates an actual case of damage done by *Zootermopsis* and reported in the "Architect and Engineer" for July 1930 (Light, Koch, and Bowe). The structure was a two-story frame building (26 feet × 68 feet) in Berkeley, California. It was erected about twenty-five years ago at a cost of about $4,500. The foundations were of concrete and the general construction conformed to common practice for frame buildings.

> One detail of good construction was, however, disregarded in this building, as has been true, unfortunately, in many other instances, that is, that the exterior foundation should never terminate below the finished grade. In this particular instance .... the top of the foundation was from one to two feet below the ground adjacent to the building (fig. 92).
>
> The 2 × 8 untreated sills had been destroyed for practically the entire distance around the building and in some places had collapsed to considerably less than an inch in thickness. The outer end of the joists on either side of the building were partially or entirely destroyed for two or three feet of their length except over the basement at the rear of the building and for a considerable distance on one side of the building the joists had been crushed to less than one-half their original depth of twelve inches. The lower ends of the studding were, with very few exceptions, found to be damaged for a distance of from four to eight inches above the floor, this distance depending upon the adjoining ground level. The floor was also found to be infested close to the outer walls and towards the front of the building where there was practically no ventilation under the floor. In a number of places the lower ends of the tongue and groove boards had been destroyed to such an extent that the paint was all that remained.
>
> The cost of repairs was approximately $950 and the repair work involved the raising of the exterior foundation, replacement of joists and floors on either side of the building and cutting off the lower part of the exterior walls. This repair cost could easily have been avoided by not filling in around the building or by an expenditure of $30 or $40 for additional foundation work at the time the building was constructed.
>
> In this particular case the pound of cure cost considerably more than the ounce of prevention, the repairs amounting to more than 20 per cent of the original cost of the building, whereas proper construction would have added no more than 1 per cent to cost of building.

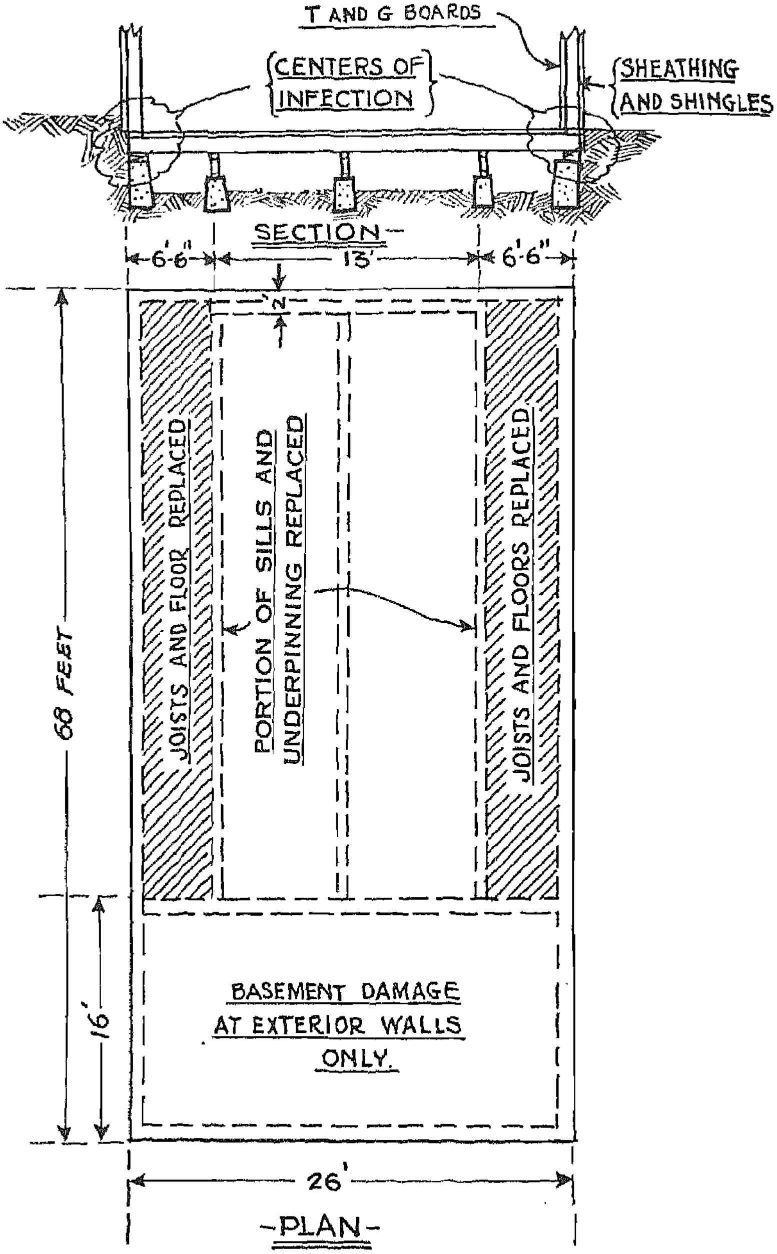

T AND G BOARDS
CENTERS OF INFECTION
SHEATHING AND SHINGLES
SECTION
6'6"
13'
6'6"
2'
JOISTS AND FLOOR REPLACED
PORTION OF SILLS AND UNDERPINNING REPLACED
JOISTS AND FLOORS REPLACED
68 FEET
16'
BASEMENT DAMAGE AT EXTERIOR WALLS ONLY.
26'
-PLAN-

Fig. 92. Plan of a building in Berkeley, discussed in the text (p. 279), showing location of damage by the common damp-wood termite, *Zootermopsis angusticollis*, and the conditions responsible for the infestation—earth filled in against wooden structures.

Such cases of extensive damage by the damp-wood termite are rare, but in the light of these instances we cannot state that the species of *Zootermopsis* are economically unimportant. On the other hand, of course, we cannot state that they are as destructive as *Reticulitermes*, or even *Kalotermes*. In conclusion, we can sum up the importance of *Zootermopsis* as follows: In areas favorable to this genus from the standpoint of temperature and humidity and where it is comparatively abundant, *Zootermopsis* is potentially of economic importance. However, it can be controlled, and almost eliminated as an economic factor, by those construction and treating methods used to prevent the far greater damage to be expected from fungus and subterranean termites.

Zootermopsis nevadensis (Hagen)

Zootermopsis nevadensis, the more common of the two California species of the genus *Zootermopsis* found in drier areas and higher altitudes, is smaller and darker than *Z. angusticollis*. It is found from Vancouver Island, British Columbia, south to central California along the coast and east to Montana. It is a forest-dwelling species, primarily of the transitional zone, being able to withstand more rigorous climatic changes than *Z. angusticollis*.

The castes found in this species are the same as those found in *Zootermopsis angusticollis,* namely the soldier and the reproductive, the latter with its three forms. The soldier of this species is often confused with the soldier of *Z. angusticollis,* but can be identified by its longer and more straight-sided head and relatively longer mandibles. The alate is smaller than the alate of *Z. angusticollis,* and, instead of the cinnamon-brown color, is a dark chocolate-brown. The supplementary reproductives are the same color in both species.

In its biology *Zootermopsis nevadensis* is similar to *Z. angusticollis*. For this reason a detailed account of its development will not be given. Instead, only those instances in which it varies from *Z. angusticollis* will be noted.

The records of swarming received by us show that the majority of swarms occur in July, August, and September, although there are reports for almost every month of the year. They are affected by climatological conditions, swarms usually occurring on warm, humid, quiet evenings. The flight of this species is more rapid and fly-like than that of *Z. angusticollis*.

Eggs are laid in the spring following the fall flight. The eggs average about 1.41 mm. in length when laid, and at the time of hatching are about 12 to 15 per cent longer. The first laying consists of between fifteen and twenty-two eggs. The eggs are cared for by the royal pair. The newly hatched young have an average head width of 0.70 mm., ranging from 0.63 to 1.73 mm. The incubation period varies from forty-eight to sixty days, the average being fifty-four days.

Soldiers are produced in from thirty-two to thirty-eight days after the first nymph hatches. The average head width of soldiers produced in this short time is 2.35 mm. The method of development is the same as in *Z. angusticollis*.

This species is likewise positive to moisture and air currents, and negative to light. It is more rapid in its responses than is *Zootermopsis angusticollis.*

The alates, soldiers, and supplementary reproductives are developed in the same manner and in approximately the same time as in *Zootermopsis angusticollis.*

Information concerning the duration of instars has not been secured.

ECONOMIC SIGNIFICANCE

From the standpoint of potential economic significance, *Zootermopsis nevadensis* ranks with *Z. angusticollis.* Fewer instances of destruction have been reported for this species, probably due to the fact that it is not so prevalent in the densely populated areas and in those in which intensive collecting has been done. We can present two instances of the attack of this species on ties, *viz.*, burnettized ties at Applegate, Placer County, California, have been reported attacked by this species, and at Lakeside, Oregon, ties in three-quarters of a mile of track were attacked by *Z. nevadensis,* together with *Reticulitermes hesperus.* Miscellaneous reports include attacks on poles, docks, a few houses, and one bridge.

We cannot relegate this species to the group of economically insignificant termites, although existing records would tend to place it there. Potentially it is of economic importance, and no doubt a more extensive survey of the areas in which it is common will reveal more extensive damage. Like its congener, however, it does not present a separate problem, but will be controlled, so far as man-made structures are concerned, by the use of construction methods designed to prevent damage from fungus and subterranean termites.

Zootermopsis laticeps Banks

Zootermopsis laticeps, the third and least known species of the genus *Zootermopsis,* is found in Arizona and New Mexico. Very little work of a biological nature has been done on this species. Townsend (1893) published a short paper supposedly on *Z. angusticollis* collected near Las Cruces, Dona Ana County, New Mexico. Banks (1906) described the species and concluded from Townsend's measurements that *Z. laticeps* rather than *Z. angusticollis* was the species concerned in the latter's paper.

From the meagre records of its occurrence it is evidently limited in distribution to the southeastern portion of Arizona and the southwestern portion of New Mexico. It swarms during June and July. Snyder (Banks and Snyder, 1920) states that the habits of this species are similar to those of *Zootermopsis angusticollis.*

From all reports, *Zootermopsis laticeps* seems to be of little economic importance, usually attacking rotten native timbers. However, Townsend reports that these termites were found in a group of large cottonwoods *(Populus fremonti),* which were in an unhealthy condition from termite attack. Possibly. therefore, they have the ability to attack and kill live, healthy trees.

CHAPTER 25

THE DESERT DAMP-WOOD TERMITE, *PARANEOTERMES SIMPLICICORNIS*

BY

S. F. LIGHT

Paraneotermes simplicicornis Banks is difficult to place in the habit types designated in this report (chap. 12). It belongs to the family Kalotermitidae. all other known species of which are wood-dwelling termites. Indeed, as seen in wood, it presents the usual picture of a wood-dwelling termite. For this reason, and because of the fact that it is found in desert regions, it was formerly called the desert dry-wood termite (Light *et al.*, 1930). Recently Light *(in press)* has shown it to have many of the habits of earth-dwelling termites, as brought out below. Although it penetrates the earth at times, it does not build covered runways to reach wood above ground, and hence does not fall into the habit type of subterranean termites (p. 132). Since its moisture demands are high, it confines its attacks largely to moist wood in or on the soil. From the point of view of economic significance, it falls, therefore, among the damp-wood termites (p. 129) and is so allocated here, being designated the desert damp-wood termite.

The various castes of *Paraneotermes* are readily distinguishable from the corresponding castes of dry-wood termites of the same region (see key, pp. 206–207), particularly from those of *Kalotermes minor;* and are even more readily distinguishable from other damp-wood termites *(Zootermopsis).*

The abdomen of the nymph of *Paraneotermes* ordinarily has a spotted appearance, due to the fact that the dark contents of the intestine show through in places. The soldiers have low, flat heads (fig. 70), brown or yellowish brown in color. The mandibles are short, and are thick near the base, but with narrow tips. The third segment of the antenna shows little if any enlargement or special chitinization. The alate is dark brown throughout, including the wings. The wing venation is characteristic of the subgenus *Paraneotermes* and not readily confused with that of any other genus or subgenus. The median vein of the wing runs near the radius sector, but is not so heavily chitinized as is the radius sector; the cubitus vein curves toward the front near the tip of the wing, and joins directly or by connecting branches with the radius sector.

Previous to the work of the Termite Investigations Committee, *Paraneotermes simplicicornis* (=*Kalotermes simplicicornis* Banks [Banks and Snyder, 1920]) was known from but two collections, one made in Texas (Snyder, 1920) and one in Arizona (Snyder, 1926*a*). We now know that the species has a remarkable range, extending from Barstow, California, within about a hundred miles of the Pacific coast, to Cotulla, Texas, within about the same distance of the Gulf of Mexico, and from at least as far north as Las Vegas, Nevada, south on the west coast at least as far as San Blas de Sinaloa in Mexico. It will be noted that this range embraces largely arid, semi-desert, or desert country. Within this area *Paraneotermes* is most abundant in the sand dunes, the washes, and the stream beds of the desert margins, where it occurs most commonly in dead roots and buried branches of the mesquite *(Prosopis)*. It occurs less commonly in the smoke tree *(Parosela spinosa)*, and in more arid portions in several smaller desert shrubs, notably California Dalea *(Parosela californica)* and shad scale *(Atriplex* sp.) It is often found also in certain trees characteristic of the stream bed flora of the northern portion of its range, particularly in desert willow *(Chilopsis)*.

In wooded canyons bordering the more arid areas, it is to be found in roots, stumps, and logs of cottonwood and sycamore, usually associated, in certain areas at least, with one or both of the two important typical dry-wood termites, the *commn dry-wood termite (Kalotermes minor)* and the southern dry-wood termite *(K. hubbardi)*. Light found all three species in the same log in Copper Butte Canyon, Arizona (Snyder, 1926*a*), and all three were found attacking poles in Tucson, all being present in the same pole in some cases.

Where cultivation and irrigation have introduced new physical conditions and new plants, this termite has been found in dead wood of cottonwoods and pepper trees (Indio and Palm Springs, California), in living hedge plants (Coachella, California), and attacking living young citrus trees (p. 287). More extensive observations will undoubtedly add to the series of host plants, both natural and introduced.

Of some of the natural plant reservoirs, as the mesquite, only dead wood seems to be attacked. In the case of the smaller desert plants, such as the California Dalea and *Atriplex*, the colony is usually found in plants either in an apparently healthy condition or at least partly living. Some colonies are found in the dead plants, but these seem to be exceptions; such colonies are not found in the long dead, thoroughly dry plants, although their deserted workings are often found in them.

Much remains to be known concerning the biology of this interesting termite. Such features of its biology as are known are most unusual and of great interest. As pointed out above, it seems to be confined to arid areas and extends its range into the desert beyond the limits of any other termite of its family (fig. 87*a*). It would naturally be expected, therefore, that it was adapted to low moisture requirements. Laboratory experiments have shown, however (see chap. 4), that its actual moisture requirements are high, and field observations have shown it to confine its activities either to wood which is moist, due to its being partly or entirely buried, or to living or partly living plants, in which the sap provides the moisture.

While *Paraneotermes* belongs to the family of wood-dwelling termites (Kalotermitidae), and itself presents in many ways the appearances and behavior of a wood-dwelling termite, yet it exhibits numerous features of behavior essentially subterranean (Light, *in press*), briefly summarized below.

1. Alates, colonizing pairs, nymphs, and soldiers all readily, rapidly, and effectively penetrate soft, fine, damp soil (dune sand). The fact that such soil is largely confined to the desert areas may explain their limitation of range.
2. They make fairly permanent runways through sand.
3. The colonizing pairs enter earth in preference to wood.
4. Colonizing pairs are unable to enter sound wood.
5. Runways have been found through the soil to wood attacked.
6. Colonies encountered in wood differ from the colonies of wood-dwelling termites in that (1) no eggs or first instar nymphs are present; (2) no primary reproductives are found (a single contrary instance); and (3) no supplementaries are found.
7. It is assumed, therefore, that the colonies usually observed in wood and plants are outlying groups of larger colonies maintaining connections with a central reproductive center, supposedly located in decayed wood deep in moist soil.

ECONOMIC SIGNIFICANCE

The desert damp-wood termite, *Paraneotermes simplicicornis*, is a common cause of damage to untreated poles and posts within its range, especially in the vicinity of mesquite clumps. Since the attack is greatest at or just below ground level, the point of greatest stress for a pole, it is capable of doing serious damage in certain areas. Butt-treating should eliminate such attacks because (1) this species confines its attacks to wood below ground (fig. 34*e*); (2) the colonizing pairs do not enter wood directly; and (3) the species does not build covered ways to reach wood above ground. When treatment is made standard practice, these termites should become a negligible factor as regards posts and poles.

Only a few cases are known in which damage to house timbers was done by *Paraneotermes*. Here, again, proper construction will obviate any damage, since constant moisture and ground contact of wood are necessary for their entry and successful attack.

For a discussion of the interesting attacks on citrus trees by this species see chapter 26.

CHAPTER 26

TERMITES AND GROWING PLANTS

BY

S. F. LIGHT

The literature of tropical agriculture and horticulture records numerous cases of damage done by termites to growing plants. Rubber, tea, coffee, cacao, citrus trees, sugar cane, and even teak suffer damage from this cause.

Perhaps the most interesting case of termite attack on living trees is that by *Kalotermes tectonae* on young teak trees in Java, which has been exhaustively investigated by Kalshoven (1930). Here the colonizing pair enters some small piece of dead wood, such as the butt of a small dead branch. From this the developing colony works into the main trunk, where its activities cause a characteristic swelling of the growing tissues.

Of more economic importance is the infestation of the tea bushes of Ceylon by *Kalotermes militaris* and *K. dilatatus*. This situation has been carefully studied by Jepson (1927–1929), who has accomplished control by the injection of Paris green powder (1929). In 1930 he was able to state *(in litt.)*, "200,000 tea bushes have been successfully treated. We secure 100 per cent kill without injury to the bushes."

In the more temperate regions termite attacks on living trees and plants are typically sporadic and local, and are not known to be of economic significance. These cases, like most of those important in tropical agriculture, owe their occurrence largely to the presence of unprotected dead wood through which the termites make their original entry. The presence of colonies of wood-dwelling termites in the dead wood of living trees is a widespread phenomenon in California. Such colonization by *Zootermopsis angusticollis* has been found in walnut, maple, pear, sycamore, madrone, laurel, and redwood. In the vast majority of cases, however, especially in the southern half of the state, the species involved is the common dry-wood termite, *Kalotermes minor* Banks. Such colonies have been found in nearly all of the common orchard trees, as also in many shade and ornamental trees, including living palms, and in the native trees, especially those of the canyons, most notably in the sycamore. In some cases such infestations result in injury to the tree, especially where the supply of dead wood is limited or the infestation is of long standing. Where dead wood is limited, the termites eat close to the cambium and cause its gradual recession, and where the infestation is of long standing they may tunnel out the branches or trunk so extensively as to materially weaken the tree, making it incapable of withstanding storm or crop weight. In the great majority of cases studied, trees suffer little harm from those invaders which confine their activities to the natural dead wood. Even such colonies, however, while apparently doing little damage at the time, are of potential economic significance, since they give rise at certain seasons to colonizing alates which subject surrounding trees and nearby wooden structures to danger of infestation, and they weaken the tree as it ages.

The damage resulting from such termite attacks could be prevented or reduced, and the degree of infestation limited to a negligible figure, by systematic removal of dead wood and the sealing or painting of exposed surfaces to reduce the probability of entry of colonizing pairs; or by the injection of poisonous dust to destroy colonies (chap. 38) where removal of infested parts is impracticable.

Certain other less numerous cases of damage by termites to living trees fall in a different category. While caused by termites of widely separated systematic position and very different habits, they have in common the facts that (1) the attack is from without, the termite colony having its origin and permanent center elsewhere; (2) the attack is directly or indirectly on the living portion of the tree; therefore (3) it is potentially and in most cases actually more destructive, often resulting in the death of the tree; and (4) the damage is accomplished much more rapidly, in weeks rather than years, as in the other type of attack.

The species involved in these sporadic attacks on living plants represent an amazing diversity as to classification and habit group. The four species brought to the attention of the Termite Investigations Committee as responsible for such attacks, listed below, include representatives of the three common families and belong to four different genera and three different habit groups. Only one, the western subterranean termite, ranges widely in the United States. The other three belong to the desert fauna confined to the southern border areas. They are

1. *Paraneotermes simplicicornis* (Banks), the desert damp-wood termite
2. *Reticulitermes hesperus* Banks, the western subterranean termite
3. *Heterotermes aureus* Snyder, the desert subterranean termite
4. *Amitermes acutus* Light, the western tube-building desert termite

All four of these species have been found to be responsible for the death of some of the trees attacked. Their methods of attack differ as widely as do their systematic positions. One *(Paraneotermes simplicicornis)* kills the tree by cutting off the tap root above the crown roots (fig. 93); one *(Reticulitermes hesperus)* by eating into the root stock and trunk and finally girdling the cambium (fig. 94); and the other two, by eating away the outer living portion of the tree from without, under cover of earthen galleries.

Paraneotermes simplicicornis (Banks)

This interesting termite (chap. 25) is classified with the wood-dwelling termites. It has, however, adapted itself to life under desert or semi-desert conditions by the assumption of a semi-subterranean habit (Light, *in press*), and by availing itself of the wood of living plants.

It depends largely upon the mesquite for food, and, in more arid places, upon such desert shrubs as the California Dalea *(Parosela californica)*, desert willow *(Chilopsis)*, and the smoke tree *(Parosela spinosa)*. It is also abundant in certain localities in smaller, less permanent plant species, such as quail brush and shad-scale *(Atriplex)* and the arrow weed *(Pluchea sericea)*. It has not been definitely reported as extensively attacking any cultivated plants except young citrus trees, but it has been taken in pepper trees and cottonwoods, and unconfirmed reports accuse it of killing certain hedge plants. Certainly, its attacks on desert willow in shaded canyons, where it eats out the entire heart to a distance of several feet above ground, suggest that with the increase of shade in irrigated areas it may become of some economic importance.

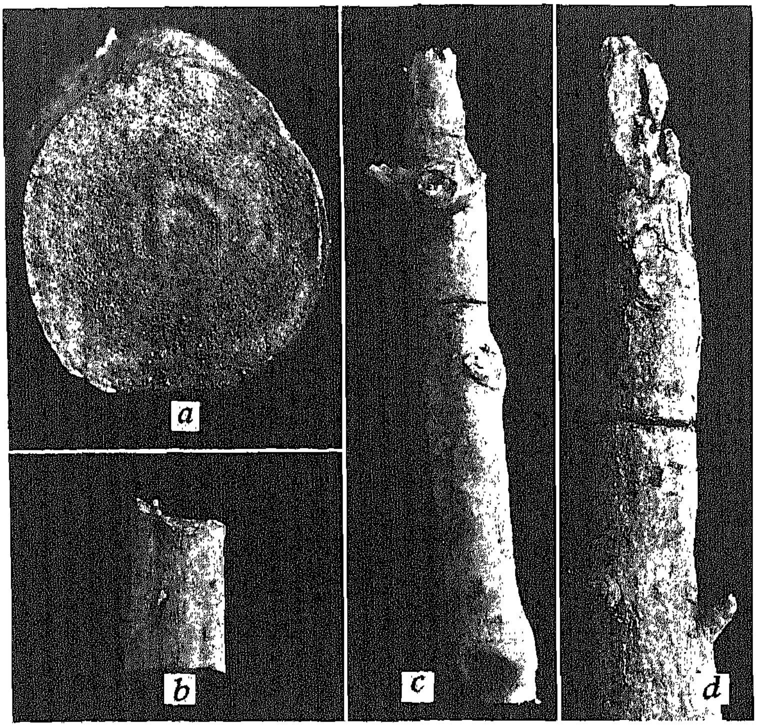


Fig. 93. Samples of damage to young citrus trees by *Paraneotermes simplicicornis*, the desert damp-wood termite. *a*. The upper end of the piece shown in *b*, enlarged to reveal the distinctive feeding pattern made by these termites in making their characteristic cuts. *b*. A portion cut off above and below by two completed transverse cuts. *c*. An incipient transverse cut. *d*. Transverse cut nearly completed. Here the dead wood at the tip of the root stock, above in cut, has also been attacked.

The attacks on young citrus trees are of quite another type, entirely different indeed from anything reported for any other species of termite. No warning signs indicate the early stages of attack by this species. The first external indication is the shriveling of the leaves, which is followed by the rapid dying and drying up of the tree over a period of about a week. Slight lateral pressure shows such trees to be unattached below, and when the earth is removed they are found to be cut square across at one or more levels (fig. 93). One of these cuts, the last executed where there is more than one, is located above the crown roots, and of course results in the immediate death of the tree, cut off thus from any effective ground connection.

While these attacks have only recently come to our attention, Dr. Ralph H. Smith, of the Institute of Tropical Agriculture at Riverside, California, who first called them to our attention, tells us that in the literature of economic entomology of the last fifty years there are several references to similar damage in California.

Only four orchards are known to us to have suffered in this way during 1928–1930, although it seems probable that other cases have escaped notice, being attributed to ants, etc. These orchards are all located in the Coachella Valley in southeastern California. In one orchard about 9 trees were killed in 1929, and 2 or 3 in 1930. In another, 9 were killed in 1929, and 20 in 1930. The third lost about 30 trees in 1929, and reported a loss of 150 in 1930, including a few two-year-old trees. Some 130 of these were reported to have been examined and to show the characteristic horizontal transections. The orchards were on recently reclaimed land which was previously extensively overgrown by such woody plants as mesquite and arrow weed. There seems every reason to believe that the condition was due to the activity of colonies present in the underground portions of the original growth before the ground was cleared.

These attacks were almost entirely confined to trees less than six months in the ground. Since the attacking termites enter through the burlap wrapping of the ball, it seems perfectly feasible to prevent such attacks by dipping the ball in some poisonous solution, such as Paris green; or the wrappers could be poisoned by the nurseryman before wrapping. The present expectation of damage would not justify the cost of such treatment, however. Nothing can be done in the case of the individual tree, since fatal damage is accomplished before there are any external evidences. Certain precautions are possible which would no doubt effectively reduce the danger of loss: (1) Remove all roots of woody vegetation when the land is cleared. (2) Reject trees with much exposed or dead wood on the rootstock. (3) At the time of planting turn back the burlap cover of the ball, so that termites moving along it will not reach the tree. The second precaution seems advisable, since practically all of the trees killed showed such conditions. The third is suggested by the fact that the termites reach the wood of the tree from the burlap where it approaches the trunk near the top of the ball. Whether the cost of these operations would be justified remains to be seen.

Reticulitermes Holmgren

Various species of this genus have long been known (Banks and Snyder, 1920) to attack, more or less sporadically, living trees and shrubs, and even flowering plants and crops. Occasionally they damage or kill the plants by tunneling out the stalk. This has been reported to the Committee in the California region for chrysanthemums, asters, etc., and there seems reason to believe also that their attacks on roots are a drain on the plants. Their attacks on trees are usually confined to dead portions, and the damage done is slight.

On occasion, particularly in young, recently transplanted trees, these attacks may result in death. Such a case occurred in Berkeley, California, and was reported to the Committee by J. E. Wyman, arboriculturist for the city. A number of young camphor trees had shown signs of weakness, such as dying back of the terminal buds, leaves turning yellow and dropping off, etc. When finally removed they were found to be extensively hollowed out in the roots and lower part of the trunk (fig. 94), and to contain numbers of the western subterranean termite. The termites had not only eaten the wood, but had almost completely girdled the bark (fig. 94*b*). Careful examination of unsuccessful plantings of trees may show the number of such cases to be significant. It seems probable that such attacks will be found to be correlated with an exposure of dead wood in roots or rootstock at the time of transplanting.

Heterotermes aureus Snyder

This species is the most northerly representative of the pantropical genus *Heterotermes* (=*Leucotermes* Silvestri). There are reports from various parts of the world of sporadic attacks on living plants by the species of this genus. They have been found attacking sugar cane in the Philippines (Light, 1921*b*) and various flowering plants on the west coast of Mexico (chap. 28). The natural reservoir of *H. aureus* is the giant cactus and the cholla cactus of the desert areas.

In all the cases mentioned above the attack is from below by way of the roots. A very different type of damage was discovered in two young citrus orchards in the Coachella Valley, California. In these instances the termites had built earthen galleries from the ground up over the trunk, under cover of which they had attacked the bark, weakening the tree and in some cases causing its death. In one orchard two trees were attacked in 1929 and several more in 1930. Here the damage was preceded by an attack on the cardboard wrapper with which the trunks were protected, and extended to large areas of the green bark. These trees showed extensive chlorosis, one to such a degree as to indicate that if left untreated death would have resulted. In these cases removal of the wrapper and the attacking termites, and the use of fertilizer to strengthen the tree, solved the problem.

With regard to the second orchard our information is less satisfactory. At the time of examination in 1929 several trees were found with the character-

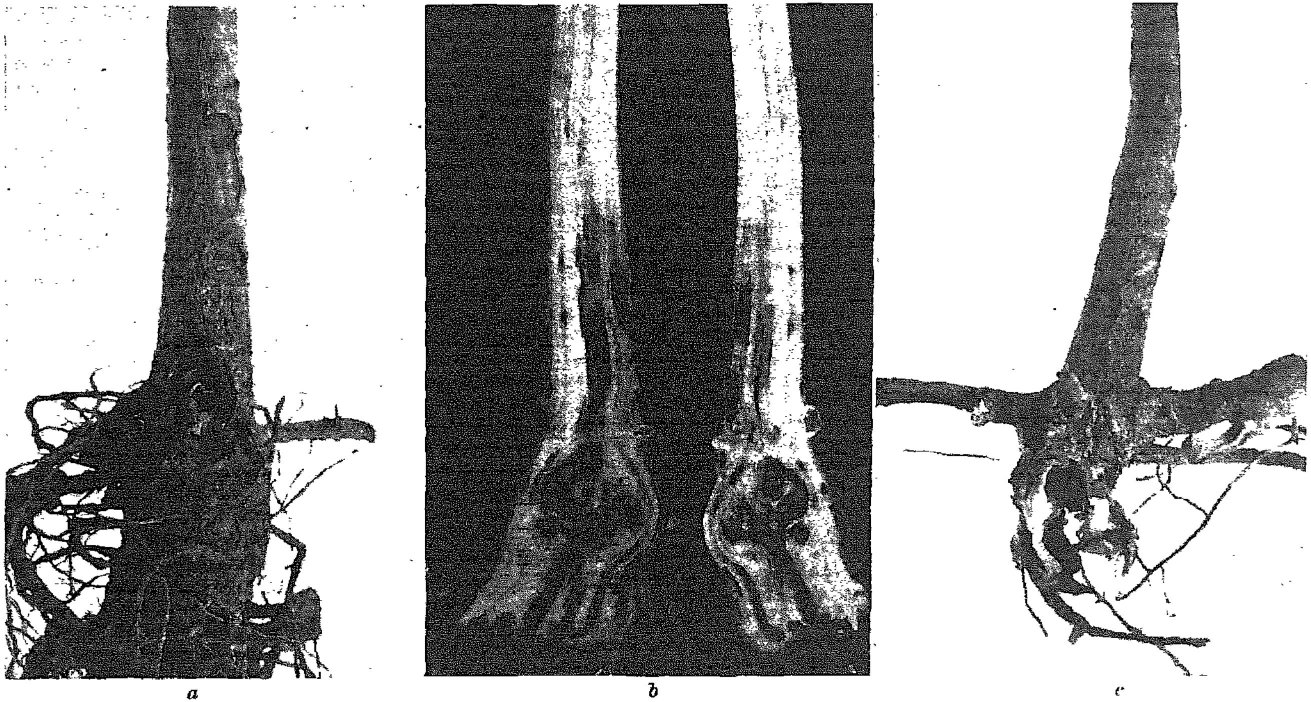

a b c

Fig. 94. Photographs showing damage to young camphor trees in Berkeley, California, by the western subterranean termite. *a* and *c*. Trees showing surface damage. *b*. Sections of *a* to show internal damage.

istic earthen galleries and damage to the green bark. Investigation showed that the attack had first been made on the dead wood exposed in the bud region at or near the ground level, and that from this the galleries had been extended to considerable areas above, where the green bark had been extensively eaten away. The caretaker reported that one hundred trees had been built over in this way and that fifty trees had been lost. How many of the trees lost were killed by *Heterotermes* attack was not known.

Amitermes acutus Light

Amitermes acutus Light, the western tube-building desert termite, is one of the large desert termites (chap. 18) of the subgenus *Gnathamitermes* (Light, 1932*a*). The species of this subgenus have the habit of building extensive earthen tubes and galleries over desert vegetation (fig. 65) and over posts and poles, under cover of which they eat away the paper-thin weathered layer of wood or, in the case of small, thoroughly weathered desert plants, the entire plant, leaving the tubes to puzzle the uninitiated. They have been known on occasion to build similar galleries over living portions of creosote bush (*Larrea tridentata*) and the giant cactus (*Cereus* sp.), their attacks resulting in the death of the bark over the areas covered.

Amitermes tubiformans has been known to be of economic importance at times in certain areas, due to its destruction of forage plants in the manner described above (Banks and Snyder, 1920). No other species of the genus had been known to be of any economic importance, however, until Dr. Smith discovered an attack by *A. acutus* on young citrus trees near Redlands, California. The following brief account is arranged from Dr. Smith's letter.

> Recently we had another case of termites in a planting of young orange trees, 8,000 in number, near Redlands, California. These trees were planted out about two months ago. I examined the situation on August first and found three or four dozen trees more or less affected. In several instances tubes had been built up completely around the trunks and in a few cases the tubes extended out over the short branches that had been pruned back, completely concealing them. The injury was confined entirely to the feeding of the termites on the exterior bark, although in a few cases the bark was eaten completely through to the wood, causing the death of the tree.

To sum up, termites in certain local areas in the tropics are responsible for very extensive damage to living plants, principally tea, rubber, and teak. In the temperate zone, however, their attacks on living plants are sporadic and of minor economic importance.

CHAPTER 27

THE TERMITES OF HAWAII, THEIR ECONOMIC SIGNIFICANCE AND CONTROL, AND THE DISTRIBUTION OF TERMITES BY COMMERCE

BY

E. M. EHRHORN

HISTORICAL DATA

Early records show that termites have existed in the Hawaiian Islands for many years. The first available publication, dated 1883, mentions two species, then erroneously identified by Robert McLachlan (1883) as *Calotermes castaneus* and *Calotermes marginipennis*. These are now known to be, respectively, *Kalotermes (Neotermes) connexus* Snyder and *Kalotermes immigrans* Snyder.

Again, in the *Fauna Hawaiiensis* the same two species are listed by Perkins (1913*b*), quoting McLachlan (1883), with the following notes as to habitat:

> *Calotermes castaneus*
>
> Hab. All the islands, in the mountain forests. Colonies often occupy the whole of a large tree.
>
> *Calotermes marginipennis* Latr.
>
> Hab. Towns and settlements. Abundant, and destructive to the wooden buildings of Honolulu.

In the introduction to the *Fauna Hawaiiensis*, Dr. R. C. L. Perkins (1913*a*) refers to these two species and states that the identifications by McLachlan are given on the examination of winged examples only, and he doubts their correctness. Again, he says that the smaller species, *Calotermes marginipennis*, is clearly introduced, inhabiting houses and woodwork throughout the Islands, but it is not a forest insect. It has done much damage in Honolulu and other settlements, attacking many of the choicer woods. On the other hand, the larger species, *Calotermes castaneus (Neotermes connexus* Snyder), is a true forest insect, being particularly fond of dead Koa trees *(Acacia koa)* or the dead parts of living trees.

The habits of *Calotermes marginipennis (Kalotermes immigrans* Snyder*)* as recorded by McLachlan (1883) and Perkins (1913*b*) do not agree with our present observations of the species. We find that this species seldom occurs in houses and woodwork. It is mostly found in dead tree stumps, utility poles, and fence posts, but the most common infestations are in the dead branches of shrubs, such as Kiawe or Algaroba *(Prosopis juliflora)*, Guava, Lantana, and *Acacia farnesiana* (Klu). I know of only two instances of damage to houses by this species. The foundation timbers of a church in the Ewa district were badly damaged by this species. I am told that at the time the church was built, over thirty years ago, the locality was covered with thick underbrush, such as Guava, *Acacia farnesiana*, Lantana, and other shrubs. The other case was the floor of a dwelling at Schofield. The infestation was near an open fireplace. I found that the wood used as fuel was brought in from the field and consisted of Guava and other woods, some of it dead wood. It appears that the termites left the wood and got into the floor.

It seems probable that much of the damage to houses, furniture, and woodwork reported by McLachlan (1883) and Perkins (1913*a*) was the work of *Cryptotermes piceatus* Snyder (1922). The separate identity of this species was not realized until 1917, when soldiers of the species were discovered which evidently belonged to a different genus from that of *Kalotermes immigrans*. Winged forms had been collected as early as 1904, but no study was made at that time. Mr. Arthur C. Alexander as a young student in 1884 remembers seeing his father's Koa desk infested by so-called borers, and reports to me that the pellets which came from the damaged wood at that time looked exactly like those he now finds in his house and furniture. The common name of this species, "Old Borer," is still in use.

Under the title *Termites or White Ants in Hawaii*, D. T. Fullaway (1920) discusses the economic importance of two other species of our fauna, *Cryptotermes brevis* Walker and *Coptotermes intrudens* Oshima, now known as *Cryptotermes piceatus* Snyder and *Coptotermes formosanus* Shiraki, respectively, the last identification by S. F. Light *(in litt.)*.

In an article on *New Termites from Hawaii, Central and South America, and the Antilles*, Dr. T. E. Snyder (1922) describes as new species *Neotermes connexus* and *Kalotermes immigrans*, the species identified by McLachlan (1883) as *Calotermes castaneus* and *C. marginipennis*, respectively, and a new variety of dry-wood termite, namely, *Neotermes connexus* var. *major*, collected by W. H. Ashmead at Kaiwiki near Hilo on the Island of Hawaii. In a later paper (1924*b*) he describes a new species under the name of *K. marjoriae*, from material collected by H. W. Henshaw at Hilo, Island of Hawaii, July 1900. Neither the new variety nor the new species has been collected since. In the case of both of the common species a great variation has been observed in size and color of individuals collected even in the same colony, and it seems probable that the new variety and new species will prove to be variants of the two common species.

Other articles dealing with Hawaiian termites are by Anon. (1917), Bryan (1915), Fullaway (1920, 1926*a*, 1926*b*), Muir and Swezy (1926), and Swezy (1913, 1914).

From the foregoing it will be seen that we have four common species and one rare or doubtful species and a doubtful variety, a total of five species and one variety of termites in these Islands; these are placed in two families and four genera as listed below:

FAMILY KALOTERMITIDAE

Kalotermes immigrans Snyder }
Kalotermes marjoriae Snyder } dry-wood termites of the plain.
Kalotermes (Neotermes) connexus Snyder }
Kalotermes (Neotermes) connexus var. *major* Snyder } termites of the forest.
Cryptotermes piceatus Snyder—the powder post termite.

FAMILY RHINOTERMITIDAE

Coptotermes formosanus Shiraki—the subterranean or soil-nesting termite.

Kalotermes immigrans, K. marjoriae, and *Neotermes connexus* and its variety have not as yet been classed as injurious species from an economic standpoint. They have been in the Islands for a long period and, in fact, are probably endemic. *K. immigrans* is abundant in Washington Island, and the Pacific Entomological Survey has found both species in the Marquesas (Light, 1932*b*) and *N. connexus* in Fiji (Moorea). More recently *K. immigrans* was found to be abundant in the Galapagos Islands, where it was taken many times by Dr. Larsen of the Zaca Expedition (Light, MS.).

Cryptotermes piceatus and *Coptotermes formosanus* are doing considerable damage to dwellings and other woodwork, the latter species being by far the most serious one we have to deal with at the present time. *C. formosanus* was undoubtedly introduced from the Orient, where it is the only species of this genus in Japan (including Formosa) and the mainland of South China. *Cr. piceatus* has been thought to be an introduced species, but the Pacific Entomological Survey took it in the Marquesas (Light, 1932*b*), and it seems possible that it is endemic.

KEY TO THE SPECIES OF TERMITES FOUND IN HAWAII

ALATES

1. Wing scales small; costal venation weak, no oblique branches between radius sector and margin..........*Coptotermes formosanus* Shiraki
1. Wing scales large; costal venation heavy, with numerous oblique branches between radius sector and costal margin.......... 2
2. Median of forewing weakly chitinized about one-half way between radial sector and cubitus..........*Kalotermes immigrans* Snyder
2. Median of forewing strongly chitinized, running much nearer to radial sector than to cubitus..........*Kalotermes (Neotermes) connexus* Snyder
2. Median of forewing weakly chitinized, running up to join radial sector near or beyond middle..........*Cryptotermes piceatus* Snyder

SOLDIERS

1. Head ovate with large tubular fontanel in front; mandibles slender, untoothed..........*Coptotermes formosanus* Shiraki
1. Head rectangular, without fontanel; mandibles heavy, with coarse teeth.......... 2
2. Head black, wrinkled, broad, truncate and excavate in front..........*Cryptotermes piceatus* Snyder
2. Not so.......... 3
3. Head narrow, rectangular, sides typically straight; third joint of antennae strongly chitinized and enlarged; hind femora enlarged..........*Kalotermes immigrans* Snyder
3. Head short and broad, sides usually convex; third joint of antennae only slightly modified; hind femora slender..........*Neotermes connexus* Snyder

THE SPREAD OF TERMITES CHECKED BY PLANT QUARANTINE

The spread of termites from other countries by means of commerce has been observed for many years. There is no doubt but that at least one of the species now found in these Islands (*Coptotermes formosanus* Shiraki) was introduced at an early date when plant inspection and plant quarantine were not practiced.

The following sample records are taken from the Division of Plant Inspection of the Board of Agriculture at Honolulu:

No. 536. *Coptotermes vastator* Light from banana stumps in shipment from Manila, P. I., July 9, 1918.

No. 787. *Reticulitermes speratus* Kolbe, taken in logs from Japan, February 1, 1922.

No. 1055. *Reticulitermes* sp. in packing of plants from Maryland, U. S. A., February 19, 1925.

No. 1210. *Cryptotermes piceatus* Snyder taken in books from China, January 7, 1926.

No. 1321. *Reticulitermes hesperus* Banks taken in wood used as stakes for plants in soil from California, U. S. A., November 19, 1926.

No. 1467. *Coptotermes formosanus* Shiraki taken in yams from Hongkong, August 22, 1927.

No. 1572. *Cryptotermes piceatus* Snyder taken in yams, Hongkong, December 2, 1927.

No. 2017. *Kalotermes* sp. taken in wood braces in box from Tahiti, January 24, 1929.

No. 2483. *Cryptotermes cynocephalus* Light taken in wood attached to orchids from the Philippine Islands, March 15, 1930.

No. 2643. *Kalotermes* sp. taken in wood attached to orchids from Mexico, July 17, 1930.

Had it not been for the strict regulations of plant inspection and the very efficient inspection of materials, some, if not all of the above species of termites might have gained admission to this Territory.

GENERAL OBSERVATIONS ON THE HABITS OF HAWAIIAN TERMITES

Habits of the Powder-Post, or Dry-Wood Termite.—The powder-post termite, *Cryptotermes piceatus* Snyder, is principally a house-infesting species. It may be found in all parts of the dwelling. It especially attacks the woodwork of the attic and from there spreads to other portions of the house, attacking ceilings, floors, walls, moldings, frames of pictures, and furniture; in fact, any product of wood. The colonies of this species are small in comparison with the subterranean species. From fifty to one hundred individuals have been collected from a nest. I captured fifty winged individuals out of fifty-eight which issued one evening from an infestation in a window frame. The nest is very simple and consists of a widened gallery which is also a storage place for pellets. When the gallery is needed the pellets are allowed to run out of small holes. The last-stage nymphs gather in this gallery and develop wings preparatory for flight. The queen never attains a large size and produces but few eggs. The attack on wood is made direct, and very often a small check or the crack where two timbers are joined is used by the colonizing pair as a point of entry.

The soldier is an interesting individual and quite distinct in appearance. The head is large, thick, excavated in front, and generally black. When the small external openings of the colony dwelling, which are usually closed with a parchment-like curtain, are opened, the active soldier will push its head up against the hole and close the opening until the nymphs can seal it again with parchment-like material.

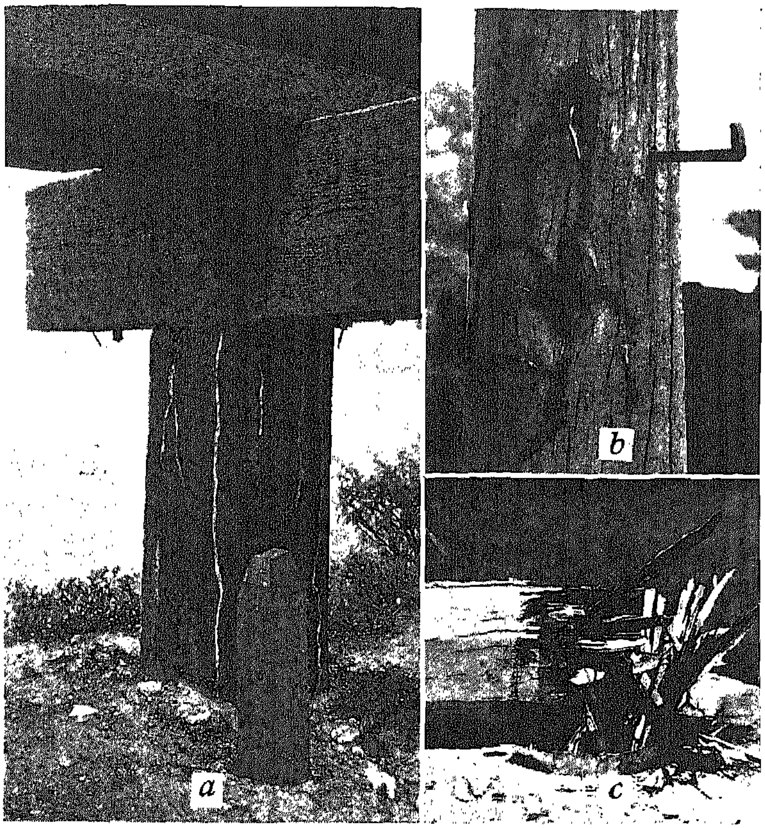


Fig. 95. Photographs of the work of *Coptotermes formosanus* in Hawaii. *a.* Covered runways from nest in ground over concrete piers to bridge and rail timbers. Below and to the right is a trap stake set to attract termites before treatment (p. 304). *b.* The earthen runways on poles, constructed by *Coptotermes*, which are a common sight in infested areas. *c.* Flagpole of a school in Honolulu, set in copper-lined concrete base, which fell during vacation in 1926, as a result of damage done by *Coptotermes.*

The wings of the adult are narrow and have a decided bluish sheen, which helps in recognizing the species. The winged individuals are males and fe-

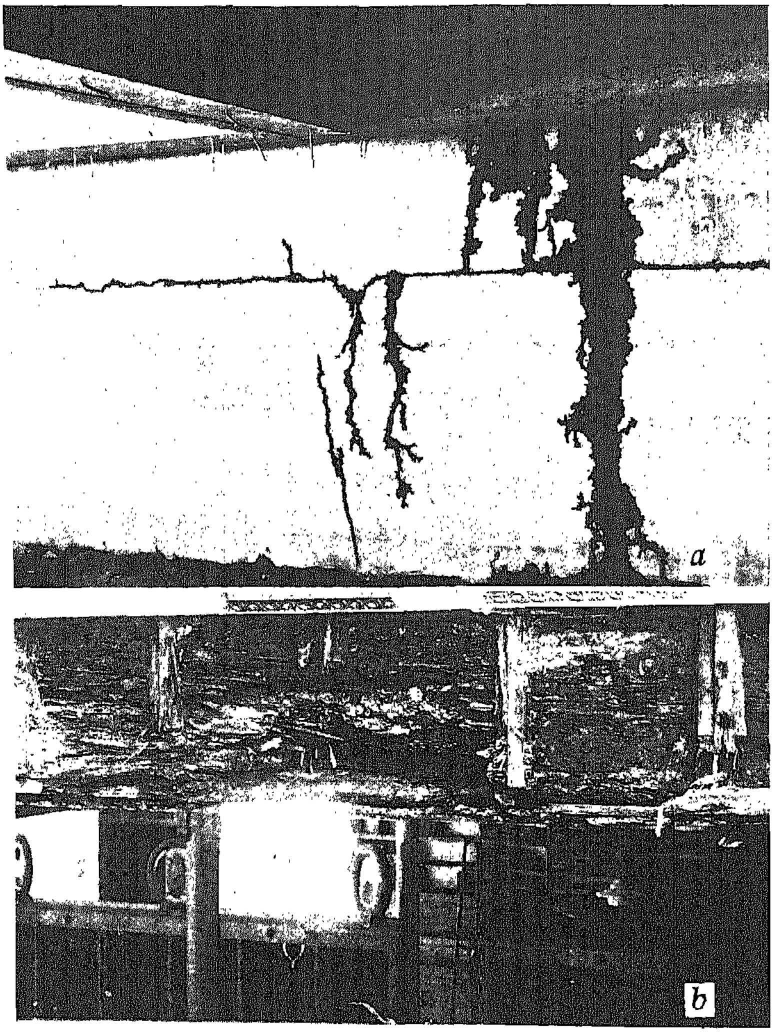


Fig. 96. Work of *Coptotermes formosanus* in Hawaii. *a*. Earthen runways on concrete wall of foundation under U. S. Post Office, Honolulu. Some forms had been left in the concrete ceiling and these were found by *Coptotermes formosanus*. Fourteen active nests were found, and 29 inactive runways where the timber had been completely eaten. *b*. A 12-inch × 12-inch girder made up of 3-inch × 12-inch Oregon pine in a second-floor store in Honolulu, showing damage by *Coptotermes formosanus*. This girder, or beam, was so badly eaten that a long screwdriver was pushed into any part of it with little pressure. A washroom on the second floor had long had a leaky pipe and the beam contained a secondary nest near this constant moisture supply. Termites in all stages were found, but no queens.

males, present in equal numbers in the nest. They take flight in the evening and are attracted to light, so that their diffusion is easily accomplished. Old infested timbers and furniture are likewise spreading mediums. This species has been reported from the larger islands of the Hawaiian group.

Habits of the subterranean or soil-nesting termite, Coptotermes formosanus.—The subterranean termite is a moisture-loving species and usually has its nest in the ground, generally away from buildings, fairly often at the base of utility poles (fig. 97) or in old tree stumps (fig. 99), fence posts, etc. This species undoubtedly obtained a foothold here along the harbor front and has spread gradually along the streets of the city by means of the utility poles. A large colony of this species contains upward of five thousand individuals. The adult flight occurs in the evening and the winged forms are readily attracted to light. Much of the diffusion of the species is brought about in this manner. The lights of street cars attract the fliers and they are carried a considerable distance into the higher elevations of the town. Many individuals have been

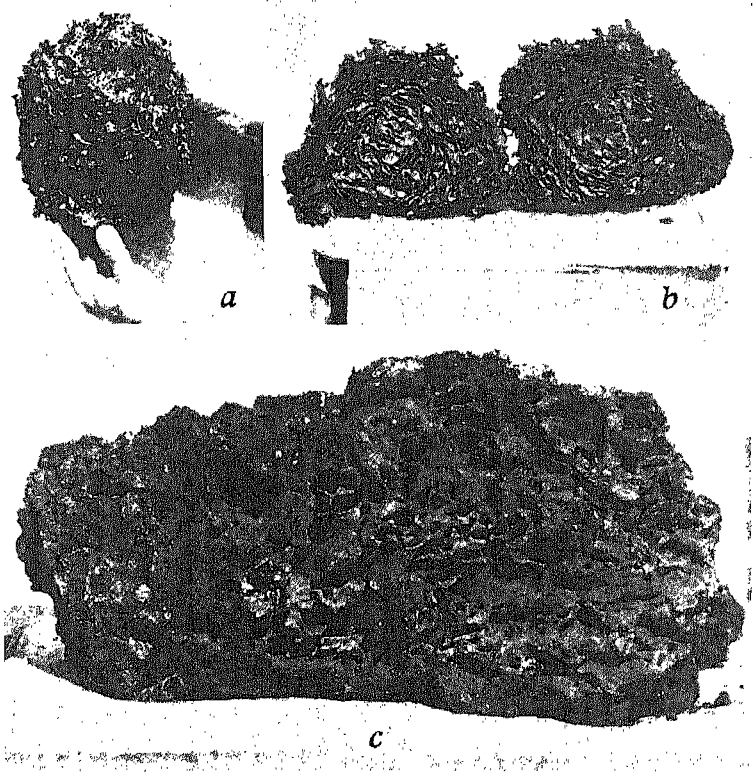


Fig. 97. Photographs of nests of *Coptotermes formosanus*. *a–b*. A paper-like nest found under a concrete sidewalk in Honolulu. A power pole formerly stood at this point and the nest was probably originally located in the butt end of this pole. *a*. Surface view of removed nest. *b*. Same nest cut in half. *c*. Hard type of nest in which much earth is used.

found in automobiles which had been standing under a street light, and the sudden appearance of an infestation in one's garage is thus explained.

This subterranean termite does not necessarily have to be in the soil, although it ordinarily has a subterranean nest. It does demand a constant moisture supply. Nests have been found near the edges of pitch-gravel roofs, with no contact with the soil. This is particularly true where the parapets are constructed of brick and lime mortar. The air currents carry the insects on top of a four- or five-story building, and if moisture conditions are right a colony can be established (fig. 96*b*). To show how necessary moisture is to this species, a colony which had a large termitarium under a roof and which was very active, soon perished when the moisture source was removed. This was done by covering the top and sides of the parapet with pitch, which prevented the rain water from penetrating the lime mortar and bricks.

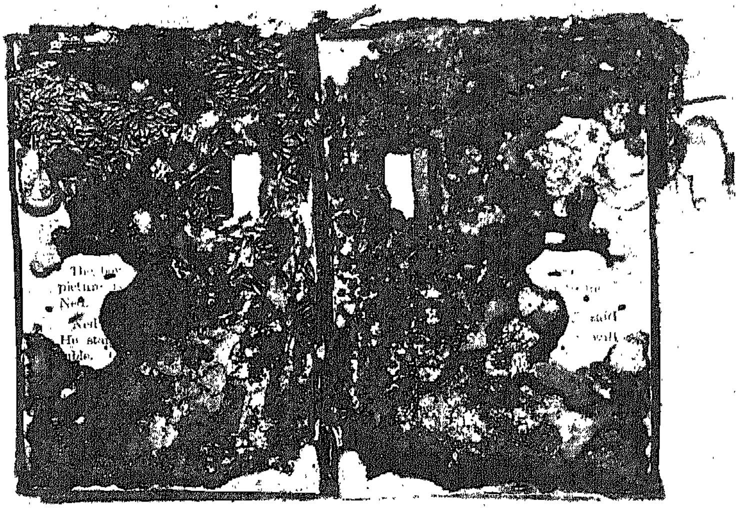


Fig. 98. The work of *Coptotermes* in a book. The termites had eaten all but a few edges, and the interior of the book was filled with their frass and many live termites, as shown here.

These termites will work their way through brick walls, and recently we found them using a hollow tile wall. The nest was in a bamboo clump and we found the termites going through the hollow tile wall up to the second floor, where a wooden bench had been set into the parapet of an open corridor. The bench was set in solid cement and the termites worked their way through the plaster below the cement and had built a covered runway about a foot long up to the wood. Nests have been found at a depth of six to ten feet, according to location and soil. At Waipahu, Oahu, on the Oahu Sugar Company's land, for example, a termite runway was followed for 165 feet, at a depth of from 1 foot to 10 feet (fig. 101). Nests have also been found in the interior timbers of steamers, barges, floating drydocks, and dredges, some of very large dimensions. These are ideal places, since ample moisture is provided by the ever-

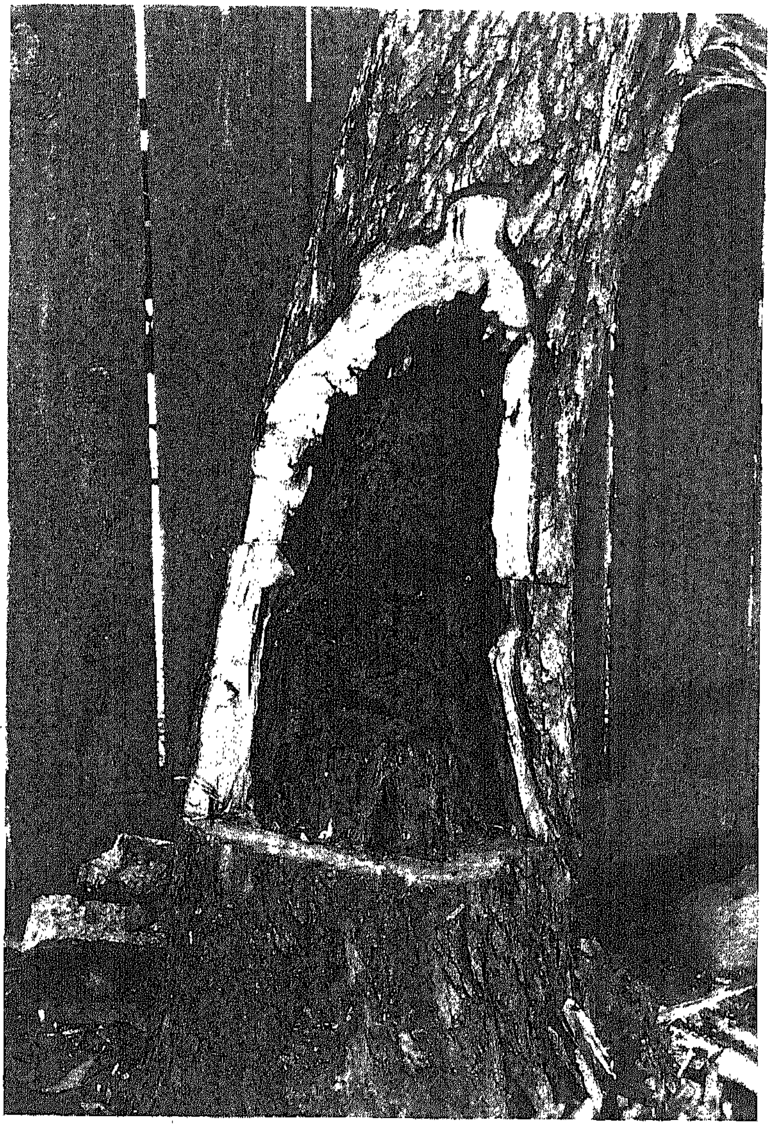


Fig. 99. Nest of *Coptotermes formosanus* in pepper tree in Honolulu. This nest extended for 14 feet up the tree trunk.

present bilge water. The lights of ships alongside wharves have no doubt attracted the winged forms.

This species has spread considerably since its first discovery. It has been located at Pearl Harbor Navy Yard, Quarantine Island, Ford Island, and Oahu Sugar Company's land along the railroad below the Waiahole ditch. It is also found at Hilo, Hawaii, and on the islands of Kauai and Lanai, although these last two infestations are now reported to have been eradicated. No doubt these outlying colonies were established by winged individuals carried by boats, automobiles, or railroad cars.

In seeking food after completely destroying timbers, this species has been known to attack asphaltum, lead, and other materials overlying woodwork. One interesting case was found in an underground conduit in which rested a lead cable. The termites worked their way through the hard conduit wall and went through the lead covering, causing a short circuit and a blowout, which called for immediate repairs.

Paper in documents and books is often attacked (fig. 98).

CONTROL

An attack on woodwork by dry-wood termites is easily detected, as it is usually near the surface and the castings of these insects, compressed pellets, which are ejected at intervals, can be found directly under an infested timber, indicating the presence of termites.

Badly infested timbers or woodwork should be removed wherever possible, and the new timber or woodwork should be thoroughly treated with creosote or other substance before replacement. Slightly infested timbers or woodwork can be treated as follows with some success: Foundation timbers and timbers in unfinished attics, with creosote either with brush or spray gun; interior finish, such as door frames, window frames, floors, etc., with Paris green, powdered arsenic, or sodium fluosilicate (chap. 38). In Hawaii we have had very good results with both methods. In treating an attic, we first use a vacuum cleaner, which removes all the pellets, dust, and other matter from the floor and other places. We then treat all visible infestations, either by the wet or dry method. After a week or two a reinspection is made, and wherever new droppings of pellets are found a close examination will reveal an overlooked infestation, which is then treated. Under such a system a thorough killing or extermination can be accomplished. The dry treatment, using Paris green or other poisonous material for interior finish, has given splendid results. In attics where the ventilators have been covered with fine mesh monel wire we find conditions better, with very few infestations, but where the ventilators are not covered the infestations are usually extensive.

The first and most important step taken to check the subterranean termite is to locate the termitarium, if possible. When this is found, carbon bisulfide can be successfully used. If indications of damage point to a very strong colony, more chemical should be used so as to furnish enough gas to reach the entire nest. If a colony, for example, is located at the base of a utility pole, we

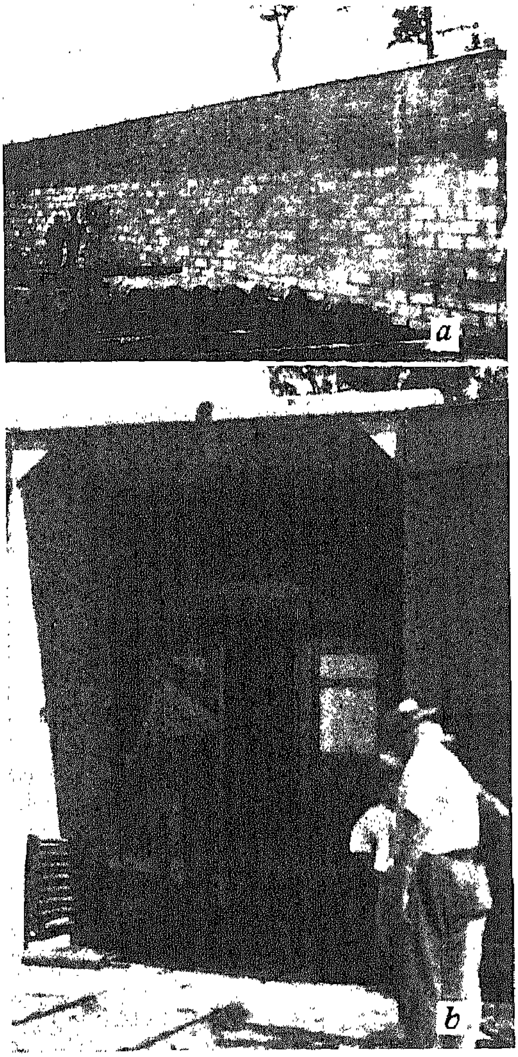


Fig. 100. Views of a dry-heat vault at Oahu Rail and Land Company's yard in Honolulu. A temperature of 150° F. was obtained by running steam from a locomotive through radiator pipes within the vault for one-half hour at 90 pounds pressure. Satisfactory kills were obtained in timbers of cars left in the vault at this temperature for forty hours. *a*. Side view of the vault showing men reading temperature on recording thermometer. *b*. The vault opened after treatment of a passenger coach.

have had very good success by first driving a crowbar into the ground alongside of the pole to a depth of three to five feet, removing the bar and in its place putting a ¾-inch pipe with funnel attached. The carbon bisulfide is poured into the funnel and runs down the pipe to near the nest; not much of the liquid is wasted, and better results are obtained. Precautions must be observed because of the great inflammability of this fluid and its gas. Carbon tetrachloride has not given as good results when applied to nests in the soil. Calcium cyanide was found effective when used in disturbed or open runways in the ground. From four to six ounces placed in the runway, covered with paper and then covered with soil gave good results; the soil was quite moist.

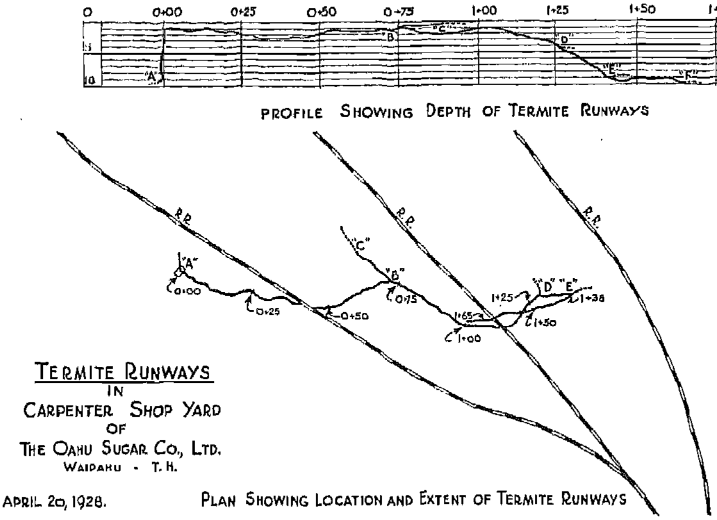


Fig. 101. Plan showing the location of a runway of *Coptotermes formosanus* which was followed for 165 feet on the Oahu Sugar Company's land, Waipahu, Oahu. Above, profile showing depth of runway throughout its course. Below, plan showing course of runway.

If the nests cannot be located, the damaged foundation timbers can be treated with Paris green or other poisons. This work must be done very carefully so as to get the poison into the damaged portion of the timber. Drilling ¼-inch holes into the timber to the center and blowing in the poison gives the best results. It becomes necessary at times to trap termites in the soil adjacent to buildings and for this purpose we have used a trap stake very successfully. This is a pointed stake 2 inches × 2 inches (fig. 95*a*) of soft white pine, new lumber of strong pine odor, 18 inches long. The stakes are driven into the soil close to the dwelling, sometimes under it, and left in place from one to two months. At the end of that period if termites have found the stake it will be badly eaten. The termites come to the stake from the nest through runways in the soil, and these runways will convey the carbon bisulfide gas to the nest. The stake is carefully removed, carbon bisulfide is poured into the stake hole, and the top of the hole is filled with a wad of paper or other material and then covered with soil. The gas, being heavy, will follow the runway to the nest. Calcium cyanide has also been used with fairly good results when the soil was sufficiently moist.

Trapping the winged form when on a flight inside a dwelling is effective in eliminating the annoyance caused by such flight, but it has, of course, little, if any, permanent effect in preventing infestation and subsequent damage. All lights in the room in which the termites are flying are turned out, except one. Under this remaining light, and close to it, is placed a large dishpan or washbowl half filled with water. The flying termites will be attracted to the light and in striking the globe will fall into the water, to which a small quantity of kerosene may be added. In about half an hour all the termites will be in the bowl, and the vessel can then be emptied into a tub of hot water.

FUMIGATION

Furniture, books, and ornaments infested with dry-wood termites can be fumigated with carbon bisulfide in tight vaults, giving them a forty-eight hour exposure to the fumes. They can also be subjected to dry heat at a temperature of 150°F. The Oahu Railway and Land Company built a concrete chamber seventy-five feet long, which holds a passenger car or two freight cars. This chamber (fig. 100) has steam pipes along each wall and the heat is furnished by a locomotive. The temperature used is 150°F., obtained with 90 pounds pressure. After forty hours' exposure to this heat, *Cryptotermes piceatus,* which infested the woodwork of the seats in the coaches, was found dead in the galleries in the wood.

CHAPTER 28

THE TERMITE FAUNA OF MEXICO AND ITS ECONOMIC SIGNIFICANCE

BY

S. F. LIGHT

Mexico is a land of widely varied terrain and climate. The semi-arid, subtemperate to subtropical conditions characteristic of the southwestern United States extend far southward on the central Mexican plateau and the western mountains and to a lesser distance along the western coast; the central portion of the narrow western coastal plain is tropical in temperature and well watered by streams from the mountains, but has relatively low rainfall, while the southern half, including Yucatan, is humid and tropical, as is also the narrow eastern coastal plain. A varied termite fauna would be expected, therefore, with a considerable amount of termite damage, particularly in the warmer areas. Previous to Light's investigations in 1929 (1933), practically nothing was known of the termite situation and, aside from scattered references to about fifteen species of the east coast, the northern border, and Lower California, the fauna was unknown.

A preliminary survey of the termite situation and the termite fauna of the west coast of Mexico was undertaken by Light in January, 1929 in cooperation with the Southern Pacific Company and the Southern Pacific Railway of Mexico. The scientific results of this investigation have been published in University of California Publications in Entomology. They reveal a termite fauna on the west coast of at least thirty-three species, of which twelve species and one genus are new to science, increasing the known species of Mexico from fifteen to forty-four, as listed at the close of this chapter.

A number of species found in the southeastern United States were found to extend their ranges far south along the west coast of Mexico. This was notably the case with the southern dry-wood termite, *Kalotermes hubbardi* Banks, which was found to be abundant as far south as Colima, the southern limit of the investigation; as also with the desert subterranean termite, *Heterotermes aureus* Snyder, which was found as far south as Mazatlan, and which is replaced to the south by two or more closely related species of the same genus, and Wheeler's desert termite, *Amitermes wheeleri* Desneux, which was common in and about Colima.

Collections have been recently received from Dr. F. H. Connell, of Dartmouth College, taken in Yucatan, which show that its fauna is in many ways similar to that found at Colima. The dry-wood termite taken in wooden structures was *Kalotermes schwarzi*, not previously reported from Mexico.

Important from the economic point of view was the finding that the common powder-post termite, *Cryptotermes brevis* Walker, heretofore known only from the West Indies and the east coast of the Americas, is one of the destructive termites in Colima on the west coast of Mexico. Of like importance was the discovery in and about Colima of a species, *Coptotermes crassus* Snyder, belonging to the most destructive genus of termites.

Except for more numerous colonies and greater amount and rate of damage there, the termite problem along the coast of Mexico as far south as Mazatlan, including such intermediate points as Guaymas and San Blas de Sinaloa, is essentially the same as that in southern California and Arizona. A single dominant species of subterranean termite is responsible for most of the damage. It attacks susceptible wood in or on the ground, and builds covered runways over impenetrable foundations in certain situations, or takes advantage of cracks or faults in construction to reach material above the ground. Similarly, a single species of dry-wood termite is responsible for most of the attacks on wood above the ground.

South of Mazatlan along the coast the picture is complicated by several of the more tropical species which occasionally or frequently attack wooden structures. Chief among these is *Cryptotermes brevis*, which, together with *Kalotermes hubbardi*, is found attacking furniture and exposed boards, but, more importantly, is found colonizing the shelves and counters of retail and wholesale stores, where it accomplishes much destruction by eating its way through merchandise piled on the shelves or in boxes, especially dry goods, books, and stationery. Their colonies are very numerous and the total damage great. One small shop in Colima reported an annual loss of 1000 pesos. Control is very difficult except by the use of treated or resistant wood. Poison dusts might be feasible in cases of light infestation, but the presence of many colonies and the likelihood of reinfestation make it probable that this method would prove unsatisfactory on the whole.

Throughout all the west coast region investigated (Guaymas to Colima) the work of the southern dry-wood termite *(Kalotermes hubbardi)* was everywhere plentiful, as shown by the old exposed galleries or the piles of fecal pellets. Since the construction is prevailingly adobe, exposed wood is chiefly seen in doors, window frames, window and door jambs, wooden shutters, floors, ceilings, and ceiling beams, and in furniture. In all of these places signs of past and present infestation were abundant. Where opened galleries were not conspicuous, careful search usually brought to light spots where a little pressure showed them to be present, and pellets were commonly encountered, indicating still other workings. In some of the cathedrals where wood was extensively in evidence in floors, pews, shrines, and altars, indications pointed to the presence of hundreds of colonies.

Here as in the areas infested by *Cryptotermes brevis*, the use of treated wood or naturally resistant wood seems to be indicated. The hard native wood used for doors and shutters was extensively attacked, and I was informed in Colima that it was rare for such wood to last longer than ten years.

The desert damp-wood termite, *Paraneotermes simplicicornis* Banks, was taken but once (San Blas de Sinaloa), but may be expected to attack wood in the ground in the arid and semi-arid regions.

The subterranean termites of the genus *Heterotermes* show an unusual ability and readiness to build covered ways over impenetrable materials, and hence are found at times attacking wood in all parts of buildings, from foundation to roof beams. Indeed, like *Coptotermes,* they often seem to prefer the roof beams of a structure. Most commonly, however, they are found attacking either wood in or on the ground or beams partly or entirely buried in adobe, or, again, paper of records or stationery supplies. In certain buildings, as in the Southern Pacific offices in Mazatlan, where they destroyed many stored records, their covered ways appeared at many places on walls and ceilings. For some distance south of Mazatlan these termites caused much trouble by destroying the crossarms of signal poles, which they reached by building over or eating through the hard, native poles.

In Colima and presumably increasingly so to the south other species of earth-dwelling termites are found attacking wooden structures. The species noted as attacking man-made structures were the yellow-headed nasute, *Nasutitermes (Subulitermes) mexicanus* Light, the black-headed nasute, *N. (N.) nigriceps* Haldeman, and Wheeler's desert termite, *Amitermes wheeleri* Desneux. The first of these, and seemingly also the last, build covered ways over adobe and wood to attack certain portions, possibly only where decayed. How much real damage they cause is not known. In one case, *A. wheeleri* was found to be damaging drygoods by building its earthen galleries over them near the walls.

Much less is known of the situation on the east coast. *Cryptotermes brevis* is known to be present, and it seems probable that Snyder's dry-wood termite, *Kalotermes snyderi* Light (1933), takes the place of *K. hubbardi.* The economically important subterranean termites are not known, but it is not unlikely that in the north there are one or more species of *Reticulitermes,* and in the south either *Heterotermes* or *Coptotermes,* or both.

Equally in need of study is the situation in the central plateau. What little information we have concerns Mexico City, Tepic, and Guadalajara. Dr. Alfons Dampf reports (*in litt.*) that the mountain dry-wood termite, *Kalotermes marginipennis* (chap. 22), is destructive in Mexico City. Light found the same species active in buildings in Tepic and Guadalajara, and one or more species of *Heterotermes* attacking house beams. *K. marginipennis* and one species of *Reticulitermes (R. humilis)* have been reported *(in litt.)* by Mr. Walter Swan as doing damage to a hardwood floor laid on the ground, and to various parts of another building in Guadalajara. Our information here is extremely meager and the need of careful investigation is clearly indicated.

What little information we have concerning *Kalotermes marginipennis* indicates that its habits are nearest to those of *K. minor* and *K. hubbardi.* Whether exposed wood should be treated in all or in part of this area cannot be stated until more definite information is available as to the prevalence of infestation and the extent of damage.

A list of the species of termites known to occur in Mexico is given on page 310. Keys to the genera, lists of species by the localities from which reported, as well as illustrated descriptions of many of them, will be found in the paper by Light (1933). The simple keys here given will make it possible to place the common species and genera which are known to attack wooden structures in Mexico.

KEY TO SPECIES OR GENERA OF TERMITES KNOWN TO ATTACK WOODEN STRUCTURES IN MEXICO

1. Large; soldiers with massive, heavily toothed mandibles (except *Cryptotermes brevis* which has black, wrinkled head); no workers; nymphs cylindrical, grub-like; winged forms with numerous short, oblique cross veins at front of wing; wing stubs long, overlapping the nota........ 2

1. Smaller; soldiers with slender mandibles; mandibles untoothed, with single tooth (*Amitermes*), or vestigial (*Nasutitermes*); workers present; no cross veins at front of wing; hind wing stubs very short; forewing stubs long, overlapping hind stubs, or short........ 7

2. Head of soldier flat and low, yellow-brown to red-brown, smooth above; mandibles large; winged forms with third vein of wing (media) running separately to or near the tip of wing........ 3

2. Head of soldier high and short, black, wrinkled above, truncate in front; mandibles weak; alate with third vein (media) turning forward near the middle of wing to join the second vein (radius sector)........*Cryptotermes brevis*

3. Third segment of antenna of soldier little if at all enlarged; mandibles short, thick at base, slender at tip; media of alate joining or sending branches to radial sector near tip of wing........*Paraneotermes simplicicornis*

3. Third segment of antenna of soldier clearly enlarged; mandibles longer and more evenly tapered; media of alate separate to end of wing........ 4

4. Third segment of antenna of soldier as long as or longer than all the distal segments together; soldier head pale yellow behind; mandibles slender and outbent; alate yellow with pale wings, about 13 mm. long with the wings........*Kalotermes hubbardi*

4. Third segment of antenna of soldier much shorter than succeeding joints together; soldier head darker behind, yellow to red-brown in front; mandibles short, not outbent; alate dark (*Kalotermes minor*) or about 19 mm. long with the wings, (*K. marginipennis*) or 11 or 12 mm. long with the wings, and confined to the Atlantic Coast (*K. snyderi*)........ 5

5. Third segment of antenna of soldier about as long as next two together; alate light, 11 to 12 mm. long with wings........*Kalotermes snyderi*

5. Third segment of antenna of soldier about as long as next three together; alates dark (*Kalotermes minor*) or light and about 19 mm. long with the wings (*K. marginipennis*)........ 6

6. Soldiers with a distinct tubercle on antero-lateral corner of dorsal surface of head; alates light, about 19 mm. long with the wings........*Kalotermes marginipennis*

6. Soldiers without tubercle; alate dark, about 12 mm. long with the wings ....*Kalotermes minor*

7. Pronotum (thoracic shield) of workers and soldiers flat and about as wide as head; alates with forewing scale large, overlapping hind wing scale........ 8

7. Pronotum of workers and soldiers very small, with uplifted anterior lobe; alates with both wing scales small 10

8. Soldier with elongated rectangular head and small fontanel (opening to head gland); secretion of head gland clear, fluid; wings of alates without hairs (*Reticulitermes*) or with few scattered hairs (*Heterotermes*); alates about 10 mm. long with wings 9

8. Soldier with ovate head and large tubular fontanel at front of head; secretion of head gland milky, viscid; wings of alate hairy; alate about 15 mm. long with wings .... *Coptotermes*

9. Mandibles of soldiers very slender and long, much longer than width of head; alates light brown with pale wings .... *Heterotermes*

9. Mandibles of soldiers stouter and shorter, about as long as head width; alates black with gray-black wings .... *Reticulitermes*

10. Soldier head normal; soldier mandible normal, with a single tooth .... *Amitermes*

10. Soldier head rounded, drawn out in front into long nose (fig. 5) with opening of head gland at its tip; soldier mandible vestigial 11

11. Soldier head yellow .... *Nasutitermes (Subulitermes) mexicanus*

11. Soldier head black .... *Nasutitermes (Nasutitermes) nigriceps*

LIST OF TERMITES REPORTED FROM MEXICO TO DATE AND THEIR KNOWN DISTRIBUTION IN MEXICO

1. *Zootermopsis* sp.?, Guadalupe Island, Santa Margarita Island
2. *Kalotermes (K.) occidentis* Walker, Lower California and islands of Gulf of California
3. *Kalotermes (K.) emersoni* Light, Colima
4. *Kalotermes (K.) hubbardi* Banks, western coastal plain as far south as Colima
5. *Kalotermes (K.) jouteli* Banks, Mazatlan; Socorro Island
6. *Kalotermes (K.) marginipennis* Latreille, mountains and tablelands of mainland; Socorro Island
7. *Kalotermes (K.) minor* Hagen, Sonora
8. *Kalotermes (K.) perparvus* Light, Tres Marias Islands
9. *Kalotermes (K.) platycephalus* Light, Colima
10. *Kalotermes (K.) schwarzi* Banks, Yucatan
11. *Kalotermes (K.) snyderi* Light, eastern coastal plain
12. *Paraneotermes simplicicornis* Banks, Lower California; Sinaloa
13. *Cryptotermes brevis* Walker, eastern coastal plain; Colima
14. *Cryptotermes occidentalis* Light, Tres Marias Islands
15. *Kalotermes (Calcaritermes) parvinotus* Light, Colima
16. *Kalotermes (Lobitermes) longicollis* Banks, Mazatlan
17. *Heterotermes aureus* Snyder, west coast; Lower California; islands of Gulf of California
18. *Heterotermes maculatus* Light, Guadalajara
19. *Heterotermes intermedius* Light, Mazatlan; Tepic; Jalisco; Tres Marias Islands
20. *Heterotermes orthognathus* Light, Colima; Yucatan
21. *Reticulitermes humilis* Banks, Nogales; Tepic; Guadalajara (La Venta)
22. *Reticulitermes tibialis* Banks, Lower California; Cedros Island
23. *Coptotermes crassus* Snyder, Colima
24. *Nasutitermes (N.) nigriceps* Haldeman, Mazatlan; Colima
25. *Nasutitermes (Subulitermes) mexicanus* Light, Colima; Yucatan

26. *Nasutitermes* (?) *pictus* Light, Colima
27. *Nasutitermes* (?) *colimae* Light, Colima
28. *Nasutitermes (Tenuirostritermes) tenuirostris* Desneux, Jalisco; Vera Cruz (Orizaba)
29. *Nasutitermes (Tenuirostritermes) strenuus* Hagen, Vera Cruz
30. *Amitermes beaumonti* Banks, Yucatan
31. *Amitermes cryptodon* Light, Colima; Yucatan
32. *Amitermes ensifer* Light, Colima
33. *Amitermes grandis* Light, Tepic; Guadalajara
34. *Amitermes infumatus* Light, Mazatlan
35. *Amitermes nigriceps* Light, Colima
36. *Amitermes tubiformans* Buckley, northern Mexico
37. *Amitermes wheeleri* Desneux, Mazatlan; Colima
38. *Anoplotermes fumosus* (Hagen), northern and western Mexico
39. *Anoplotermes* sp.?, Tepic
40. *Anoplotermes* sp.?, Guadalajara
41. *Hoplotermes amplus* Light, Colima
42. *Mirotermes (M.) panamaensis* Snyder, Colima
43. *Microcerotermes gracilis* Light, Colima
44. *Microcerotermes septentrionalis* Light, Colima

Chapter 29

THE TERMITE FAUNA OF THE WEST INDIES AND ITS ECONOMIC SIGNIFICANCE

BY

THOMAS E. SNYDER

From the economic viewpoint, or with regard to control, the termite situation in the West Indies is not markedly different from that in Middle America, to represent which Panama has been used as an illustration (chap. 30). The fauna is not so rich in species as is that of the mainland and, with the exception of Trinidad, which from the zoogeographical standpoint is in reality part of the mainland, no species of the destructive subterranean termites of the genus *Coptotermes* occur in this region.

The same type of "powder-post" house termites, chiefly species of *Cryptotermes*, attacks the woodwork of buildings and furniture in the West Indies as in Central America, and several species of destructive subterranean termites of the genus *Heterotermes* are also present.

Nasutitermes (Nasutitermes) costalis Holmgren is the most widespread of the termites in the West Indies which build "niggerhead" carton nests on trees (fig. 103*b*); it occurs on more of the islands, including Trinidad, than any other species in this genus; indeed it occurs on most of the islands. Other species of *Nasutitermes* also occur on the islands, and some of the carton nests made by various species are very large and are of irregular and odd shapes. On New Providence Island, in the Bahamas, a nest of *Nasutitermes (N.) ripperti* Rambur eight feet long and three feet in diameter was found on a tree trunk.

No termites occur in the West Indies which make striking and tall mound nests such as are made by *Amitermes (Amitermes) medius* Banks of Panama.

In 1922, at the request of the owners, I inspected a large frame hotel on one of the islands in the Bahamas. The woodwork and furniture of the large frame structure were thoroughly infested with *Cryptotermes brevis* Walker. In addition, the foundations had been attacked by species of *Heterotermes* and *Nasutitermes*. It was fairly easy to remedy the damage by these subterranean termites and to prevent further attack, but the powder-post termites were so intrenched that, while the use of poisons was recommended, it was felt that the real remedy would be to tear down the building and burn all of the material. As a matter of fact, the hotel did accidentally burn down not long after, thereby eliminating a huge source of infestation. If the building had been torn down the infested wood would have been resold, and this would have resulted in new centers of infestation where next used.

The officials of the Panama Canal prohibit the transportation of such infested wood from one part of the Zone to another. Recently the State of Florida ruled likewise in the case of the woodwork of a large hotel at Miami which was infested by *Cryptotermes brevis* Walker. The infested wood was put on sale but was ordered burned by the state officials. Unfortunately, the similarly infested furniture had been sold previously and ever so often the Bureau of Entomology is called upon by those who bought the "worm-eaten" furniture (fig. 102) for advice as to how to remedy the infestation.

In Cuba, Havana and most other large municipalities have building ordinances which prohibit the use of wooden floors; Havana is very strict in legislating against the use of wood for the construction of permanent buildings.

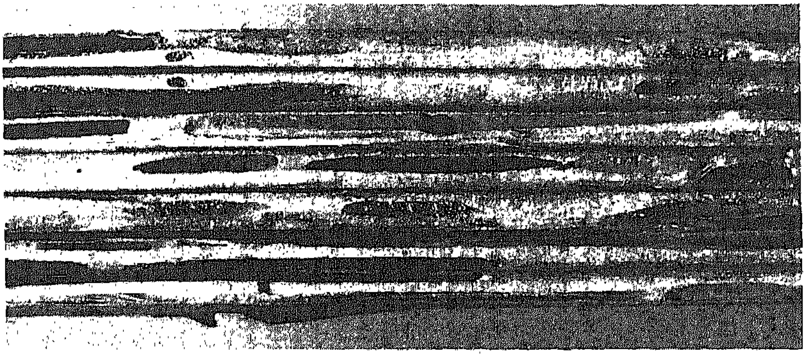


Fig. 102. Photograph of a piece of wood from furniture infested by the common powder-post termite, *Cryptotermes brevis*. Note the characteristic fecal pellets.

Damage by powder-post or house termites to the woodwork of buildings and furniture has been very marked in the past. The use of wood for the construction of buildings is, in fact, limited to the rural regions. Termite-resistant wood is favored in Cuba. Such woods as Spanish cedar (Cedrella), pitch pine, heartwood redwood, and heartwood cypress are commonly used.

In the West Indies, in general, brush treatments with preservatives of wood used in the construction of buildings is, as yet, the usual method of treatment. Recently, however, interest has been aroused gradually in wood impregnated with standard chemical preservatives, not only for use in the construction of buildings, but also in the manufacture of furniture and pipe organs.

On some of the islands furniture infested with powder-post termites has been given heat treatments or has been fumigated in closed chambers. Metal termite shields or mechanical barriers are not in general use in the West Indies. Most of the new large permanent structures are of concrete and steel. Concrete or masonry foundations, the metal termite shield, and the use of wood properly impregnated with standard wood preservatives would prevent practically all termite damage in properly screened frame buildings.

CHAPTER 30

THE TERMITE FAUNA OF THE CANAL ZONE, PANAMA, AND ITS ECONOMIC SIGNIFICANCE

BY

THOMAS E. SNYDER AND JAMES ZETEK

The agricultural development of the Canal Zone, with the clearing off of the dense tropical jungle growth for banana, pineapple, avocado, and cacao plantations, has resulted in the destruction of many colonies of termites that require a moist habitat. The intense heat of the tropical sun rendered the decaying logs, stumps, branches on the ground, and even the soil too dry and unsuitable. Large areas of the Zone were also cleared of termites by the formation of Gatun Lake; termites were eradicated from the soil by the flooding of the land, and, in general, those termites building aerial carton nests on trees also died with the flooding of the soil, although in some cases termites are living in such nests on trees killed by flooding.

In 1889 Dudley described the termites found in Panama at that time, and, while later investigations have shown that certain species are no longer present in localities in which they formerly occurred, it is not believed that the termite fauna has been radically changed.

Termites will always constitute a serious problem in Panama. Damage to the woodwork and contents of buildings and to living trees and other vegetation must be carefully guarded against. Forty-two species of termites, representing twenty-five genera or subgenera, have to date been recorded from the Zone and the nearby Republic of Panama. However, but few of these species are commonly found attacking wooden structures.

Among the powder-post termites, *Cryptotermes dudleyi* Banks is destructive to the woodwork and furniture of buildings on the Pacific slope of the Canal Zone. This house termite injures a large number of buildings and the furniture in such buildings; it is frequently associated with *Kalotermes (Kalotermes) snyderi* Light and *Kalotermes (Lobitermes) longicollis* Banks. Their presence may be detected by the impressed fecal pellets thrust out from infested wood. *Cr. dudleyi* covers all openings in infested wood with a protective coating of these excreted pellets cemented together into a hard mass or coating (fig. 103*d*). Indeed, it is not at all uncommon for these powder-post termites to make shelter tubes or even sheds of pellets cemented together (fig. 103*c*). As early as the latter part of the nineteenth century, Dudley called attention to powder-post termites, using this term to designate

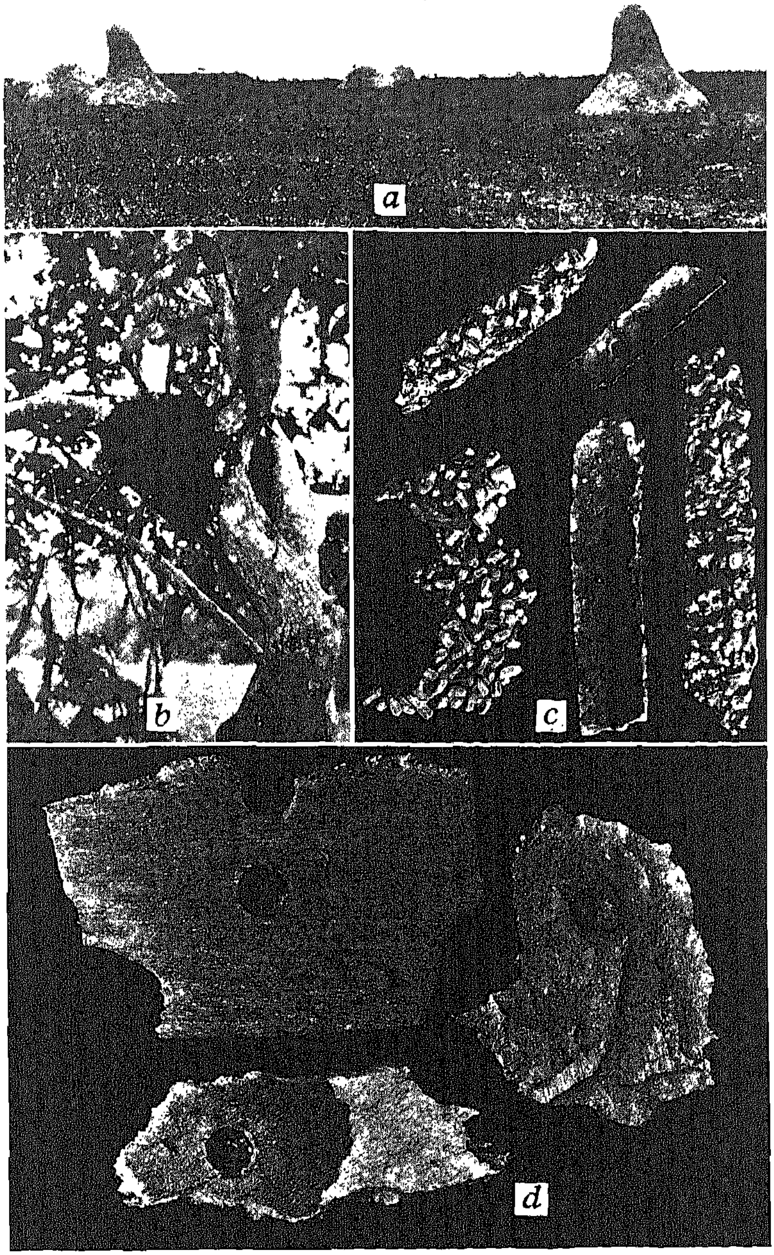


Fig. 103. Work of termites in Central America. *a*. Mounds of *Amitermes medius* in the savannah region of the Republic of Panama. Photograph by Zetek. *b*. Carton "niggerhead" nest of *Nasutitermes cornigera* in Panama. Note the covered runways up the tree to dead wood used for food, and down to make a ground contact. *c*. Shelter tubes of fecal pellets cemented together, made by the powder-post termite, *Cryptotermes dudleyi*. Enlarged. *d*. Plugs made by the powder-post termites, *Cryptotermes dudleyi*, closing up the exit holes of wood-boring beetles whose burrows they were utilizing. Enlarged.

K. (K.) snyderi, which occurs on both the Pacific and the Atlantic slopes, and *Cryptotermes longicollis,* as damaging the rolling stock of the Panama railroad and the woodwork of buildings. *K. clevelandi* Snyder is another dry-wood termite which injures the woodwork of buildings on the Pacific slope. The old practice, now discontinued, of taking down a frame building and re-erecting it at another location doubtless led to increased and more widespread damage by house termites.

The main swarming period for the dry-wood termites is during the early part of the rainy season (Dietz and Snyder, 1923). Small numbers of winged adults, however, emerge from infested wood at other times. A small swarm of *Cryptotermes dudleyi* emerging in February, 1929, from infested woodwork in the Hotel Central in Panama City, R. P., was attracted to lights in the dining room. This hotel dates back to the days of the " 'Forty-niners," when the Isthmus was crossed en route to California in the gold rush. In addition to *Cr. dudleyi,* this ancient hotel is infested by a species of *Nasutitermes,* whose earth-like shelter tubes are to be found on the stone foundation walls.

Among the subterranean termites, *Heterotermes tenuis* Hagen, *H. convexinotatus* Snyder, and *Coptotermes niger* Snyder are the most common and injurious species. All occur on both the Atlantic and Pacific slopes of Panama and injure not only woodwork of buildings, and furniture, etc. stored therein, but also living fruit trees. They swarm during the early part of the rainy season, April to June. *C. niger* is probably the most injurious termite in Panama. In addition to damaging buildings and fruit trees, together with the species of *Heterotermes,* it has injured lead-sheathed cables in manholes at the locks in the Panama Canal, causing short circuits and necessitating extensive repairs (Snyder and Zetek, 1924).

Of the termites which, while also subterranean in habit, build aerial carton nests in trees, *Nasutitermes (Nasutitermes) cornigera* Motschulsky and *N. (N.) ephratae* Holmgren are the most common and injurious. They occur on both the Atlantic and Pacific slopes and swarm from April to June, often in very large numbers. They injure not only fruit trees, but also the woodwork of buildings and contents stored therein, obtaining entrance by means of earth-like shelter tubes over the foundations. The "niggerhead" nests of these termites (fig. 103*b*) form a conspicuous part of the tropical landscape in the Canal Zone.

Other termites making carton nests are species of *Microcerotermes,* which damage fruit trees and whose nests, like those of species of *Nasutitermes,* are to be found in crotches and on the trunks of fruit trees. While other species of *Nasutitermes* occasionally are injurious and some few other termites are potentially injurious, it is believed that all of those species which are most commonly harmful have been discussed above.

In the case of termites which construct carton nests on trees, poisons in powdered form can be blown into the nests with bellows, as with the dry-wood termites, and the colonies killed in this manner. Sometimes the nests are cut off from the tree and burned or submerged in water, or broken up and the contents fed to fowls.

Of course, all of the powder-post and other dry-wood termites are potentially capable of causing damage. Among other termites, the earth-dwelling *Cylindrotermes macrognathus* Snyder and *Amitermes (Amitermes) beaumonti* Banks may become injurious with the further development of the Canal Zone (Snyder, 1926*b*). In this connection it may be mentioned that one of the most striking termites found on the Pacific slope of Panama, *Amitermes (A.) medius* Banks, constructs large mound nests (fig. 103*a*) in the savannah region of the Republic of Panama. If large numbers of these termite mounds occurred on land intended for cultivation, the land would have to be cleared by the use of steam shovels or by exploding the mounds with dynamite and

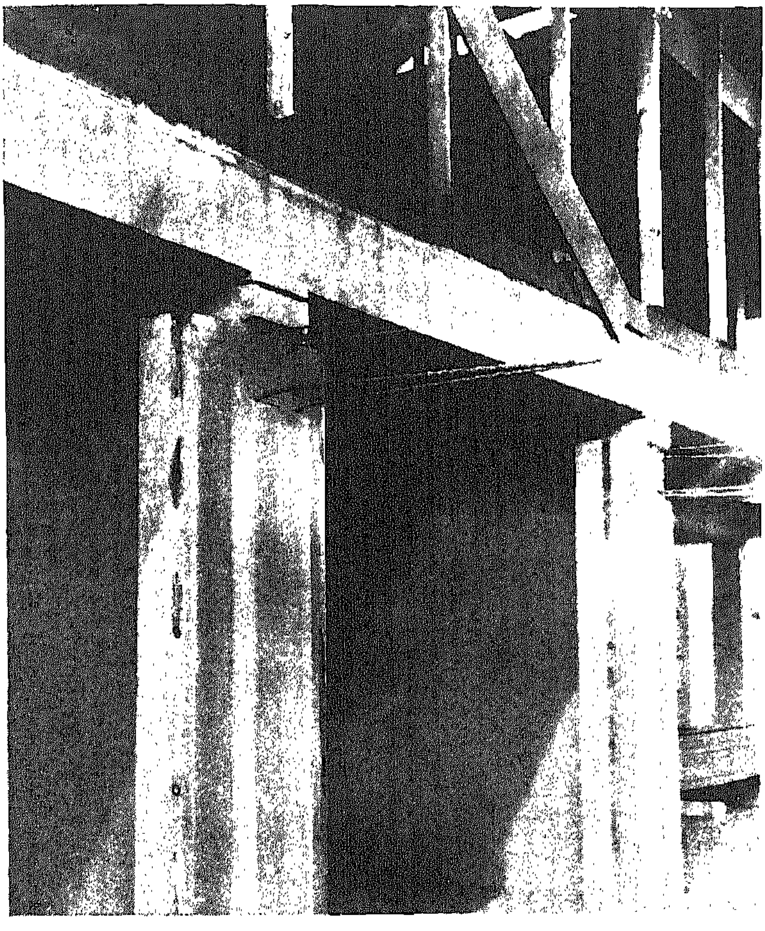


Fig. 104. Concrete foundations of a building in the Canal Zone showing grooving in concrete posts for insertion of metal termite shield. Note that the metal reinforcement rods which mark the position of the porch to be added to the building are placed *below* the shield. Note also the high foundation walls of concrete.

crushing them with a heavy caterpillar tractor, after which the broken up soil and nest material would have to be poisoned. It is believed from perusal of Dudley's accounts of the early days of Panama that this termite was once more commonly distributed in the Canal Zone than it is today.

For the prevention of attack by the dry-wood termites infesting the woodwork of buildings and furniture, screening and painting with a heavy enamel paint offer considerable protection. As a remedy, dusting dry Paris green into their galleries is recommended. Saturating the wood with orthodichlorobenzene has also been found effective. Both of these treatments have been previously discussed (Snyder, 1926*b*). The use of wood impregnated with standard preservatives is desirable in permanent structures and furniture, including pipe organs.

Mechanical barriers, such as metal termite shields, have been found to be very effective against the subterranean and the carton-nest-building termites which infest the woodwork of buildings by means of earth-like shelter tubes built over the concrete pillar foundations of these buildings, which are as a rule constructed high up off the ground. So far as is known to the writer, termites have never built shelter tubes *up over* metal shields when properly constructed on a building. In a few cases, however, they have built their earth-like shelter tubes *down* over such shields when they have been able to enter the building from sources other than those protected by shields. The use of such shields on buildings in the Zone is now a standard practice.

The old wooden buildings formerly used in the Canal Zone are rapidly being replaced by half-concrete half-wood or all-concrete buildings. In case of the half-concrete or all-concrete buildings, certain modifications made during the construction of the building have been found effective in Panama City in preventing termite attack (fig. 104).

As yet there has been but little use in Panama of timber impregnated with suitable chemical preservatives in the construction of buildings. A few buildings have been constructed with timber suitably impregnated or of naturally termite-resistant woods. At present in the Canal Zone the woodwork used above the concrete foundations is only dipped in creosote to prevent infestation by powder-post and other dry-wood termites. Where buildings are not properly inspected and kept in repair, metal termite shields may fail to give protection, and it would be advisable to use timber impregnated with standard wood preservatives and pulp or fiber board poisoned with suitable poisons.

Ever since the early days when yellow fever was rampant, the properly screened, well ventilated residential buildings constructed in the Panama Canal Zone have been regarded as standard in the planning of similar structures in the American tropics. A beginning has recently been made in the use of timber impregnated with standard wood preservatives in the construction of residences.

CHAPTER 31

THE TERMITE FAUNA OF THE PHILIPPINE ISLANDS AND ITS ECONOMIC SIGNIFICANCE

BY

S. F. LIGHT

The various islands of the Philippine Archipelago support a termite fauna rich not only in numbers of species, but in numbers of colonies and in their size and ubiquity. Some thirty-nine species are known (Light, 1930*c*) and undoubtedly many are as yet unknown, but only three are commonly found attacking wooden structures. These are the two powder-post termites, *Cryptotermes cynocephalus* Light, and *Cr. (Planocryptotermes) nocens* Light, and the subterranean termite, *Coptotermes vastator* Light.

Other species of wood-dwelling termites are found, one species, *Kalotermes (Neotermes) malatensis* Oshima, being common throughout the Archipelago; but none of them seem to attack wooden structures, their colonies being confined to natural wood, chiefly to dead wood of living trees.

The two powder-post termites are almost entirely house termites. Their collection is difficult therefore, and their distribution is not definitely known. *Cryptotermes nocens,* which is common in Manila, is known to occur also in the islands of Cebu and Negros, and both it and *Cr. cynocephalus* are probably widespread throughout the Archipelago. *Coptotermes vastator,* which is one of the commonest and most widespread species, ranges throughout the Archipelago from sea level to an altitude of at least 5,000 feet, being found in and about Baguio, the summer capital in the Benguet Mountains.

The dog-headed powder-post termite, *Cryptotermes cynocephalus,* is very small, and its colonies are small and confined to localized areas in the timbers attacked. The Philippine powder-post termite, *Cryptotermes nocens,* which seems to be more common, is somewhat larger, has larger colonies, and apparently is responsible for by far the greater part of the damage due to powder-post termites. Its attacks, while common, particularly in furniture, are seldom of any considerable economic importance; the total damage done is but a small per cent of that done by *Coptotermes.*

Much more extensive investigation as to the prevalence and extent of attacks of these powder-post termites will be required before it can be determined whether their presence will justify the use of treated or naturally resistant woods. Meanwhile, the injection of poisonous dusts into their galleries when found (chap. 38) will probably offer the best means of combating these termites.

The Philippine milk termite, *Coptotermes vastator* (Light, 1929*b*), seems to be an indigenous species; it is found attacking natural dead wood in all parts of the Islands. This species is responsible for more than 90 per cent of the annual loss from termite damage, which must be a large sum, since evidences of its attacks are common. While this is true, it must be said that this species seems to be less harmful than its congener, the oriental termite, *Coptotermes formosanus,* found in China, Japan, and Formosa, and (by introduction) in the Hawaiian Islands. The former is somewhat smaller, apparently develops less rapidly, and in smaller colonies, and does less extensive and less rapid damage than *C. formosanus;* furthermore, it seems to have fewer colonies in a comparable area than that species. On occasion, however, it does damage of a type and a degree suggestive of *C. formosanus.* The area in Pandacan, on the outskirts of Manila, for example, including the government cattle quarantine station, has a very heavy infestation. Here practically all, if not all, of the many buildings show signs of attack at various points, and the quarantine sheds themselves most of all. The termites had entered through cracks in the concrete floor and made their way by means of covered runways or through supporting pillars of hardwood to the roof rafters, which are of lauaan. These they have riddled to such an extent as to endanger the structures and make necessary replacement in many instances. The total damage to these structures is said to have approximated $25,000 in some ten years.

While *Coptotermes vastator* does not build covered runways over impenetrable materials to reach susceptible wood so readily or so rapidly as does *C. formosanus,* it does do so sufficiently often to make it wise to take all precautions to prevent damage from such attacks. One method designed to eliminate or cut down attacks by building over is the use of the termite shield (pp. 319, 550). There seems no reason to doubt, on the one hand, that the shield does discourage building over and thereby gives a decided protection, and, on the other, that the termites are quite capable of building over the shield itself and may be expected to do so in a small number of cases. This brings us to the second and perhaps most important method of preventing attacks by building over, that is, a regular inspection at intervals of three or six months by a fully informed and competent inspector (chap. 47).

One of the common causes of annoying attacks by these termites is faulty concrete work or cracks in concrete floors which are laid on the ground. Here the situation is indeed difficult, but in many cases the points of entry may be located and effective preventive steps taken, such as injecting poison into the underlying soil (chap. 40) or hermetically sealing the point of entry (chap. 48). Where the entry point cannot be definitely located and the attack is sufficiently serious to warrant the expense involved, relief may be had by boring holes through the concrete at intervals and injecting poison (see chap. 46) as extensively as possible into the soil below. In new construction in this region, poisoning of the soil (chap. 40) seems strongly indicated, particularly where the floor is to be laid on the ground.

Two other species may be found on occasion doing damage to buildings, *Heterotermes philippinensis* Light, the Philippine subterranean termite, and

Prorhinotermes luzonensis Light, the Philippine damp-wood termite. The first has much the same habits as *Coptotermes vastator,* but is much less commonly encountered. It is to be controlled by the methods recommended for *C. vastator.* The damp-wood termite, as its name implies, is found only in wood with a constant moisture supply, and hence usually in decaying wood. Being a wood-dwelling termite, it may be found in isolated wood areas subject to water drip. Removal of constant moisture supply is sufficient to destroy the present population of damp-wood termites and prevent future infestation.

Even so brief a discussion of Philippine termites as this cannot well omit some mention of certain conspicuous elements of the termite fauna which, while not ordinarily of economic significance, may become so on rare occasions. Into this category fall four species, or groups of closely related species, which are common throughout the low-lying areas of the Islands. They are:

1. The mound-building termite, *Macrotermes gilvus* Hagen
2. The small fungus growers, *Termes* spp.
3. The black-headed nasutes, *Nasutitermes* spp.
4. The horned termites, *Microcerotermes* spp.

The mounds of *Macrotermes* form a conspicuous element in the landscape of much of the cleared low-lying area of all the islands. In the mountainous and forested areas there is present in considerable numbers what seems to be the same species, but it does not construct mounds. This species is suggested to the popular mind when termites (*anai* in the common dialect) are mentioned. The species is rarely if ever of economic importance except where wooden structures have been built upon a going colony, or where the mound is constructed in a field. Efforts at destruction of termites with a view to the prevention of termite damage have often been directed at this harmless but conspicuous species rather than at *Coptotermes,* which was actually doing the damage. In certain cases the money thus thrown away ran into thousands of dollars annually.

Macrotermes often builds conspicuous broad covered runways over the bark of planted trees, and also over fence posts and other wooden structures. Under cover of these mud runways they eat away the dead outer layer of bark, but evidently do not damage the trees in any way. The same conditions apparently exist when they build over wooden structures, their efforts being usually confined to the weathered outer layers. Only occasionally do they attack the wood to a greater depth, particularly damp, partly deteriorated portions on or in the ground.

The small fungus growers, belonging to several species of the genus *Termes (= Odontotermes)* have habits similar to those of *Macrotermes,* except that in the Philippines they do not build mounds. Related species do, however, build conspicuous mounds in the Indian region. Like *Macrotermes,* the species of *Termes* occasionally attack wooden structures under cover of earthen runways, but they more often confine their activities to wood in or on the ground.

The black-headed nasutes, especially *Nasutitermes luzonicus* Oshima, are the most common builders of the conspicuous carton nests in trees, a common feature in the Philippine village or country scene. Their relatively wide covered ways, constructed of wood fragments, and running over trees, and more rarely, on buildings, are also common sights. They attack dead wood on the ground or on living trees and on rare occasions extend their activities to wooden structures, doing so only where natural wood is scarce. There are numerous related species, some with black heads, some with yellow, and some with brown, any of which may be expected at times to build over wood and in some cases to attack the wood, although the only species thus far reported as doing such damage is *Nasutitermes luzonicus* Oshima, the common black-headed nasute.

The horned termites, genus *Microcerotermes*, are among the commonest species of the Philippine lowlands. Their very narrow, semi-cylindrical, covered ways are common sights on trees, stumps, logs, posts, etc. They build hard, compact carton nests either on the ground, usually about some dead stub, as in Luzon, or in trees, particularly the coconut palm, as is more commonly the case in the southern islands (Negros, Cebu, Mindanao, etc.). The two species rarely attack buildings and then generally only the moist or decaying wood in and about bathrooms. They commonly explore houses, however, and seemingly single out for attack objects containing foreign woods, such as cameras, suitcases, trunks, etc.

The genera and species of termites mentioned as of some economic importance may be readily distinguished by the following practical key:

1.	Soldiers with square, high, brownish-black heads (fig. 5*d*); nymphs cylindrical, grub-like; galleries in wood containing pellets; no ground connection	2
1.	Soldiers with flatter (normal) yellow or reddish-brown heads (fig. 5*m*) or nasute with rounded head drawn out into a long, slender nose (fig. 5*h*)	3
2.	Smaller, head of soldier high, roughened	*Cryptotermes cynocephalus*
2.	Larger, head of soldier low, broad, smooth	*Cryptotermes nocens*
3.	Soldiers small with rounded heads drawn out into a slender nose	*Nasutitermes* spp.
3.	Soldiers normal	4
4.	Pronota broad and flat; workers with white or pale heads; soldiers with yellow heads	5
4.	Pronota tiny, saddle-shaped; workers with yellow-brown infuscated heads; soldiers with brown or red-brown heads except in *Microcerotermes*, where the soldier mandibles have a serrate cutting edge	7
5.	Head of soldier ovate	6
5.	Head of soldier narrow, rectangular	*Heterotermes*
6.	Head of soldier strongly narrowed in front with large terminal, tubular fontanel from which a milky secretion is emitted	*Coptotermes*
6.	Head of soldier not strongly narrowed in front; fontanel smaller, not at front of head or tubular; secretion yellowish, not milky	*Prorhinotermes*
7.	Workers' heads with mottled pigment; soldiers with narrow rectangular heads and serrate mandibles	*Microcerotermes*
7.	Workers' heads evenly pigmented, yellow or reddish; soldiers with broad oval heads and without marked serration of mandibles save basally	8
8.	Smaller; a single caste each of workers and soldiers; soldier mandibles with a single tooth	*Termes*
8.	Larger; two castes each of workers and soldiers; soldier mandibles without teeth	*Macrotermes*

CHAPTER 32

WOOD-BORING INSECTS WHOSE APPEARANCE OR WORKINGS RESEMBLE THOSE OF TERMITES

BY

EDWIN C. VAN DYKE

Termites are not the only wood-eating insects. In the forests, as soon as a tree dies or is injured it is attacked by a host of insects of various types which soon consume a large part of it, leaving the remainder to decompose through the agency of the various fungi and molds. Such insects are the scavengers of the forest. The first insects to attack the timber itself are the bark beetles or engraver beetles. These are small beetles which burrow through the bark and then, partly by themselves and partly through the activities of their larvae, excavate channels of various designs between the bark and the sapwood. Following these are the true borers, the wood-boring caterpillars, and larvae of several types of beetles, which, hatching from eggs deposited in cracks of the bark or wood, bore either beneath the bark or directly into the wood itself. The caterpillars are the larvae of carpenter moths, and they generally keep their channels open and enlarge them as they grow. The larvae of the beetles, the flat-headed borers or Buprestidae, and the round-headed borers or Cerambycidae, always plug up their burrows with frass and undigested woody material. The caliber of the burrow is not subject to irregular changes, though the burrows made by older larvae are, of course, larger than those made by young larvae. Such burrows are characteristic, as shown in figure 105, and should not be confused with the work produced by termites.

When the timber has dried out or cured to a considerable degree, the carpenter ants, termites, carpenter bees, and powder-post beetles appear and, when the wood commences to mold, are followed by other types of scavengers. Most of these insects remain in the forest and carry on their activities there. Those which continue to attack the wood after it has been converted into lumber or utilized by man are more limited in number. The most important of these are the termites already discussed. Others which attack lumber or other wood products are an occasional wood-boring beetle, the carpenter bees, carpenter ants, and powder-post beetles. Concerning the first, the wood-boring beetles, there are but few cases reported except in log houses made of logs with the bark still attached. Old cedar posts have on several occasions been attacked at the base, below ground, by the large larvae of *Prionus californicus* Mots., one of our largest long-horned wood-boring beetles. Numerous larvae of another type of beetle, one of the Oedemeridae, have at times been taken from water-soaked timbers of old bridges or mines. The large carpenter bees of the genus *Xylocopa* also sometimes become rather annoying by drilling out holes for their nests in posts or even in portions of buildings (fig. 107*b*). These insects and their work are also so distinct that they should not be confused with termites. The carpenter ants and powder-post beetles, on the other hand, work in such a manner that their work is often mistaken for that done by termites. These will, therefore, be discussed at greater length.

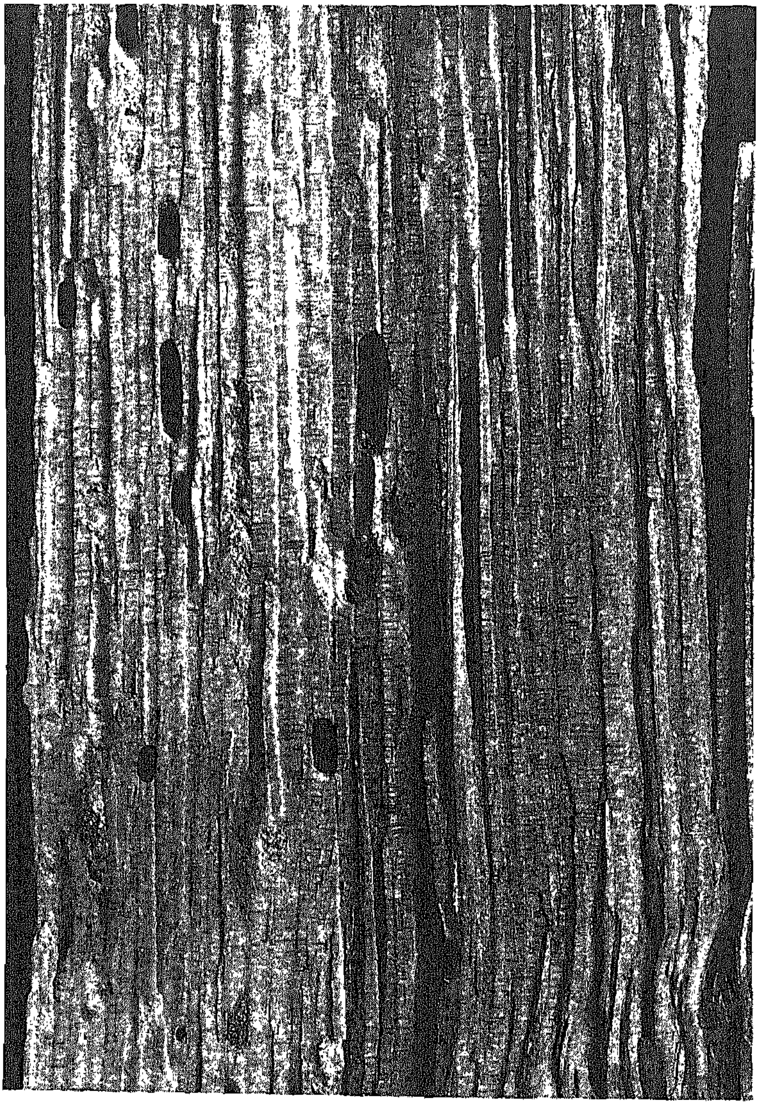


Fig. 105. Piece of Douglas fir timber showing work of a typical wood-boring beetle, one of the Cerambycidae or long-horned beetles.

THE CARPENTER ANTS

These ants are among the largest which we have in the temperate parts of the world. They all belong to the genus *Camponotus* and the species are either all black or black and red. The very large black *Camponotus herculeanus* Linn. (fig. 106), with its various subspecies, is the commonest one to be met with in our mountains. These true ants are, like the termites, social insects, living in colonies and having definite castes, the male and female reproductives and the worker. They, however, differ very much from the termites, both structurally and biologically. The true ants are, in the earlier stages, grub-like and helpless, very unlike in appearance what they are when mature, whereas the young termites are but small replicas, in appearance, of the adult workers. The adult ants are always "narrow-waisted," *i. e.*, they have the

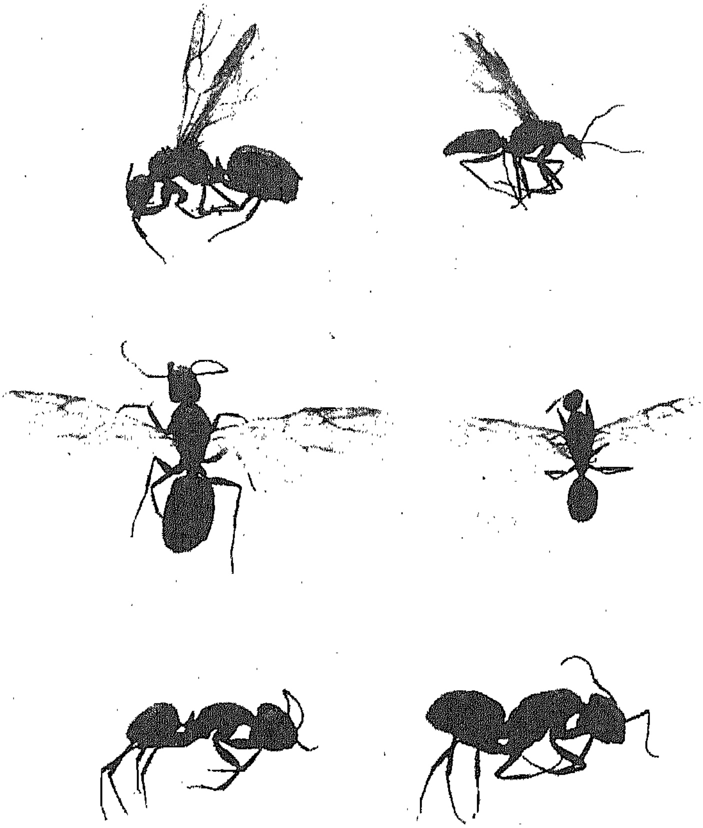


Fig. 106. Carpenter ants, *Camponotus herculeanus* var. Upper left, winged females. Upper right, winged males. Below, workers.

abdomen narrowly joined to the thorax, while the termites have it broadly joined; also, the carpenter ants have the first segment of the abdomen somewhat separated from the main portion, forming a node which is readily observed when the insect is viewed from the side (fig. 106). These nodes, one in *Camponotus* and certain other ants, and two in most common ants like the harvester ants, also readily separate the ants, workers as well as winged adults, from all other wasp-like insects. Adult ants are, when mature, either

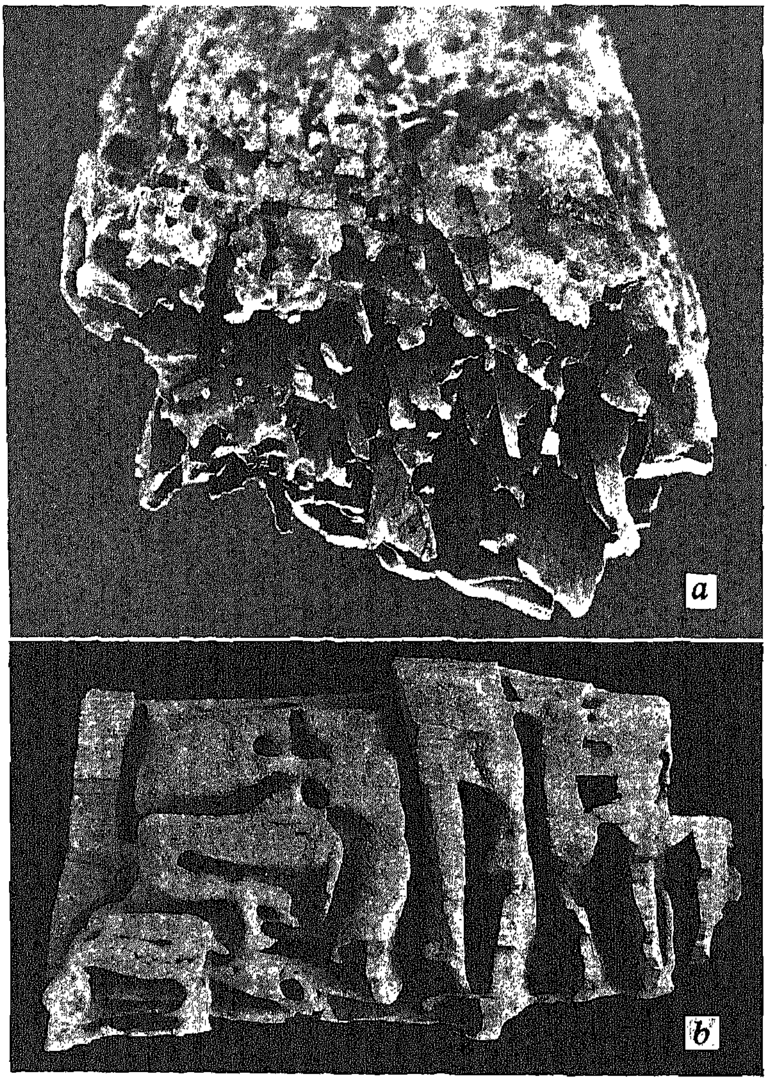


Fig. 107. *a.* Work of carpenter ants. *b.* Work of carpenter bees. Photographs by Prof. E. O. Essig.

winged males or females or wingless workers. The males and females at a certain time in the year have a nuptial flight much as termites do. They, however, pair in the air, as the termites do not. The male soon after dies, the female drops to the ground, bites off her wings, crawls to an old log or dead tree, and there excavates a cell in which she establishes herself. In a short time she lays a number of eggs which she cares for herself, and she nurses and feeds the grub-like larvae when they appear and until they reach maturity. This first brood develops into small workers which soon assume the duties of nurses and foragers, caring for the queen and the eggs and larvae of the new broods. Thus the colony progresses; in time large workers appear, and finally winged males and females. The workers, unlike the termite workers, which may be of either sex, are always sexually undeveloped females, as is the case with bees, and are always as fully pigmented as are the males and females. The various types of workers among the ants merely differ in body size and in the proportionate size of their heads. No additional neuter caste, like the soldiers and nasutes of termites, distinguished by a different appearance, is ever developed in the colonies of the true ants.

While the termites feed upon wood itself and excavate their burrows in the wood for the purpose of getting food as well as habitation, the carpenter ants merely excavate for the sake of making a home for themselves. The ants prefer dry wood and sunny exposures, the termites more often moist wood and shaded localities. The runways and other excavations made by the ants, as shown by figure 107*a*, much resemble those made by termites and are often mistaken for termites' work. The ants' runways are, however, always kept clear, free from chaff and refuse, while the termites pack away their woody feces in the unusued channels. These refuse piles are, in fact, one of the most diagnostic features in reference to termite work. Carpenter ants are rarely found in cities and towns, confining themselves almost entirely to the forests, where they dwell in old logs or enter standing trees through old base wounds. An old log house in the forest may at times be attacked, but a carefully built home even in the forest is rarely bothered. The termites, on the other hand, are probably more numerous in the cities and towns than in the country.

THE POWDER-POST BEETLES

The insects which are included under this heading are of three types, beetles belonging to three closely related and associated families, having somewhat similar life histories, and all more or less harmful to seasoned wood. They get their common name from the fact that their larvae reduce the wood to a condition of powder. This is the undigested portion of their diet. At times woodwork may be so completely honeycombed or pulverized by these insects that it will break down under the least stress. The beetles themselves, including all three groups, as well as their work, are somewhat distinctive, so we will discuss each group by itself.

THE DEATH WATCHES, FAMILY ANOBIIDAE

All of the members of this group belong to the family Anobiidae and are characteristically small, compact, more or less subcylindrical, with the head concealed from above by the overhanging prothorax (fig. 110*c*), the antennae inserted at the sides of the head in front of the eyes and having the outer three

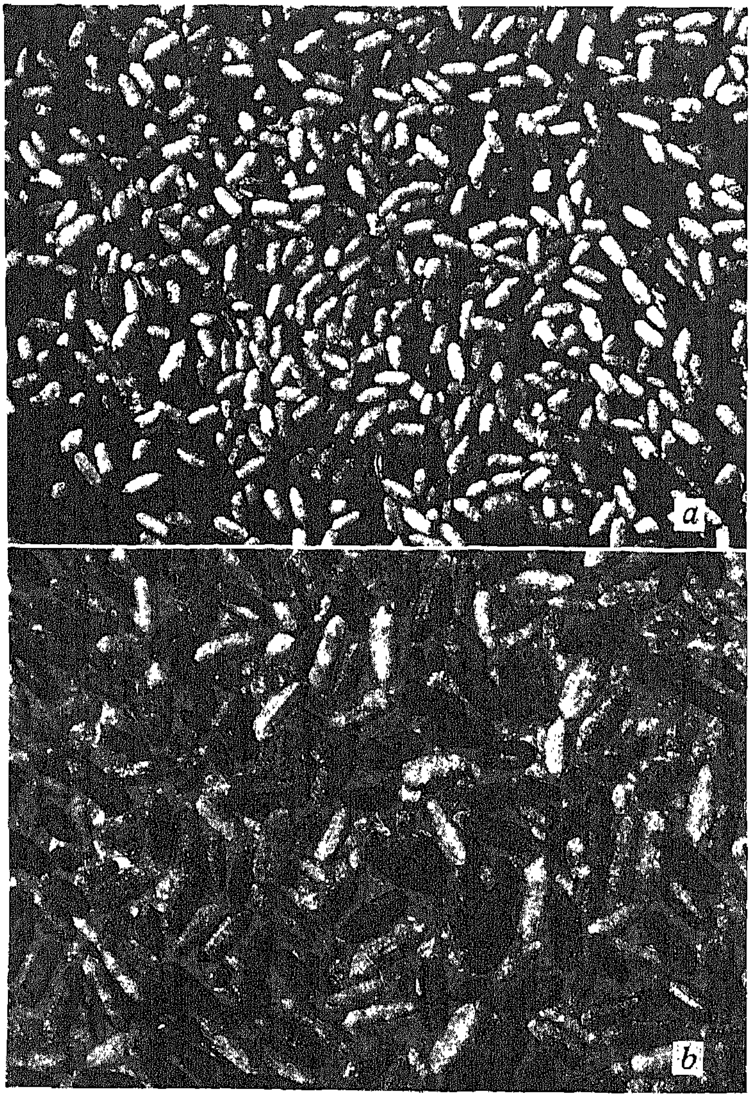


Fig. 108. Photomicrograph of pellets of Anobiid beetles. *a*. *Trichoderma* sp. *b*. *Frilletta* sp. Photographs by Dr. T. E. Snyder.

segments much enlarged, and the tibiae without well developed spurs. The adult beetles bore into the rafters and other structures of old buildings, as well as into old furniture, and lay their eggs in well protected niches. The larvae, similar to that in figure 110*d*, soon hatch and commence to burrow, and in the course of a year or so reach maturity and transform into adult beetles. These beetles breed in the same structures generation after generation,

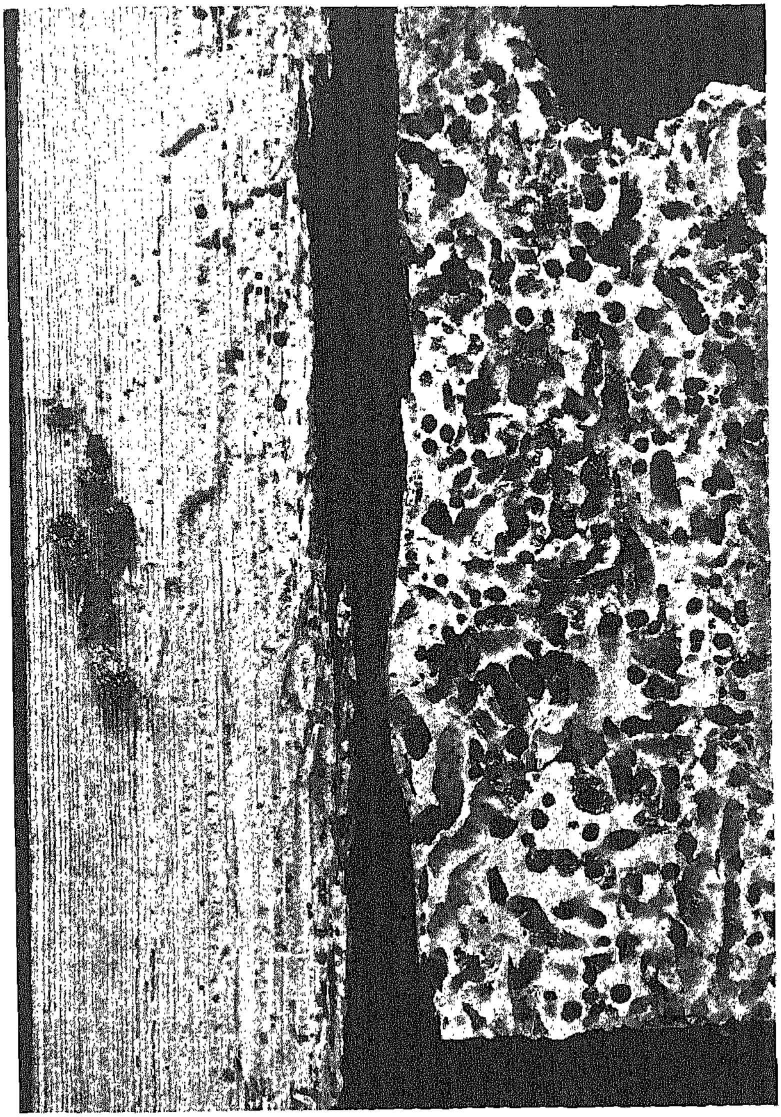


Fig. 109. Work of *Hadrobregmus gibbicollis* (Lec.). At left, portion of Douglas fir beam. At right, part of a branch.

sometimes for hundreds of years, with the result that the timbers ultimately become completely honeycombed and of course sooner or later give way. This is the cause of the collapse of many parts of old buildings. Westminster Abbey and several of the most famous of English cathedrals, as well as many on the continent of Europe, are now being overhauled as a result of the ravages produced by two species of this family. Figure 109 shows the work of *Hadrobregmus gibbicollis* (Lec.) (fig. 110*c*) one of our best known California species. At the left of the picture (fig. 109) will be seen an illustration of their work in a piece of Douglas fir taken from an infested timber in a Berkeley home. Near the center of the piece are several pupal cells. The illustration at the right shows the result of their work in an old branch. Note the completeness of the honeycombing and the fecal pellets in the burrows, a picture simulating very closely that produced by termites. Figure 108 shows the pellets of two species of Anobiids enlarged. These may readily be distinguished from the pellets of any termite by their long, narrow shape and pointed ends.

We have long known that death watches were destructive, both in Europe and Asia, but until recent years had not realized that some of our native species were also becoming injurious. The Old World species mainly attack oak and other hardwoods, while the most injurious of our species attacks, so far as known, only the Douglas fir.

The common name of death watch was given to these insects years ago by the superstitious who, hearing their tappings in their burrows at the dead of night, interpreted it as a sign that some member of their household, perhaps the sick patient that they were attending, would soon die.

THE BOSTRICHIDAE

The beetles of this family are in general somewhat similar to those just mentioned, but are usually much more elongate, and as a rule much larger, some species being an inch or more in length, and always have well developed tibial spurs. The greater proportion of the species live in the hotter parts of the world, those in our own country being dominant in the semi-arid Southwest. These beetles always prefer well seasoned wood, and in most cases confine their activities to the sapwood. Because of the fact that they almost entirely confine their attention to the wood of broad-leaved trees, the householder is but rarely bothered by them. A large dining room in a mountain resort in southern California, built of alder logs, was badly attacked by one of the larger species, *Polycaon stouti* Lec., a subcylindrical, black beetle, a half inch or more in length. The same species has also been found in the San Francisco Bay region as well as in the southern part of the state, attacking the stored products in hardwood warehouses. So far, it has been most destructive to the panels from which desks and other articles of furniture are made. The large larvae, figure 110*d*, burrow out serpentine channels in the basswood or other soft wood serving as the inner layer of the panels, and, soon after the wood has been made into furniture, transform into adults. These then burrow straight out through the mahogany or oak veneer. Our commoner species, however, work mainly in such wood as oak and

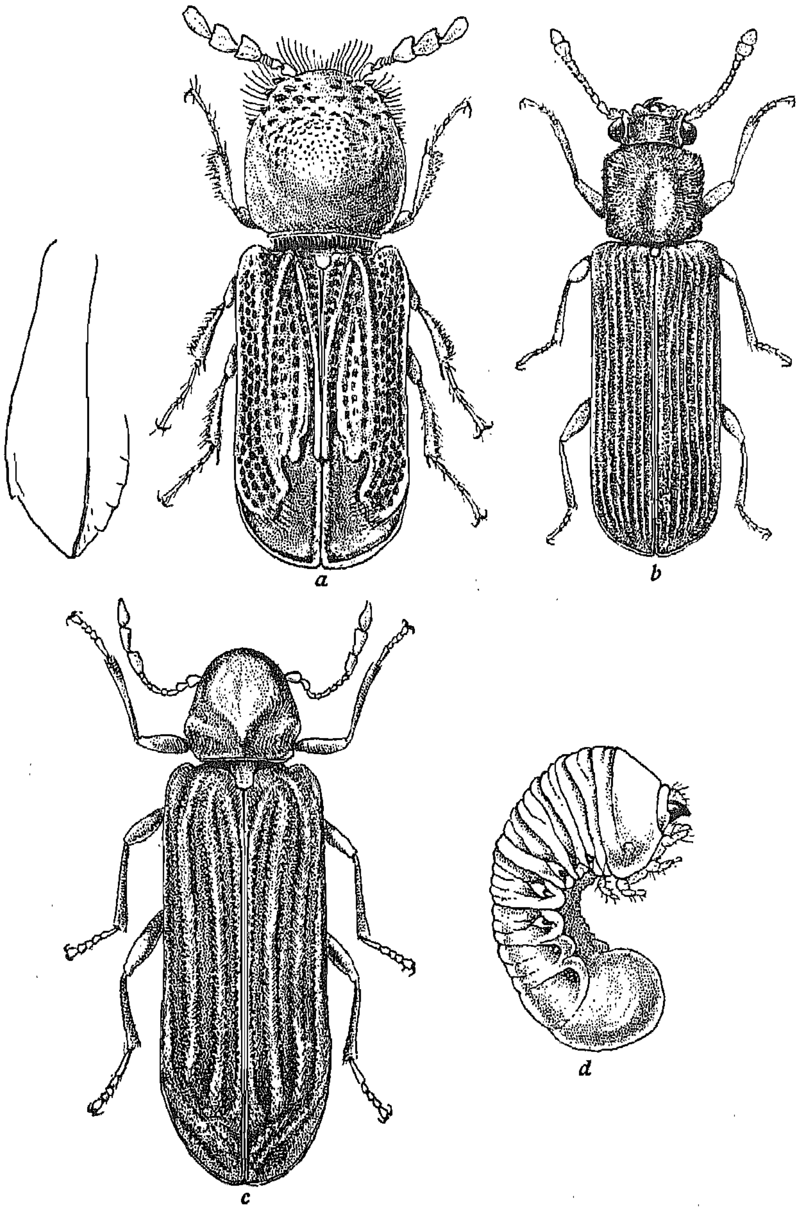


Fig. 110. *a. Scobicia declivis* (Lec.), the lead cable borer. *b. Lyctus cavicollis* (Lec.), the commonest true powder-post beetle in California. *c. Hadrobregmus gibbicollis* (Lec.), the most destructive native California death watch. *d.* Larva of *Polycaon stouti* (Lec.), one of the Bostrichidae. All much enlarged.

mesquite cordwood. The best known of these beetles is *Scobicia declivis* (Lec.), the so-called lead cable borer. As shown by figure 110*a*, this is a compactly built, rather roughly sculptured insect. It breeds freely in oak, California laurel, and similar woods. In fact, it so readily attacks the wood of the California laurel that uninfested pieces of this beautiful wood are

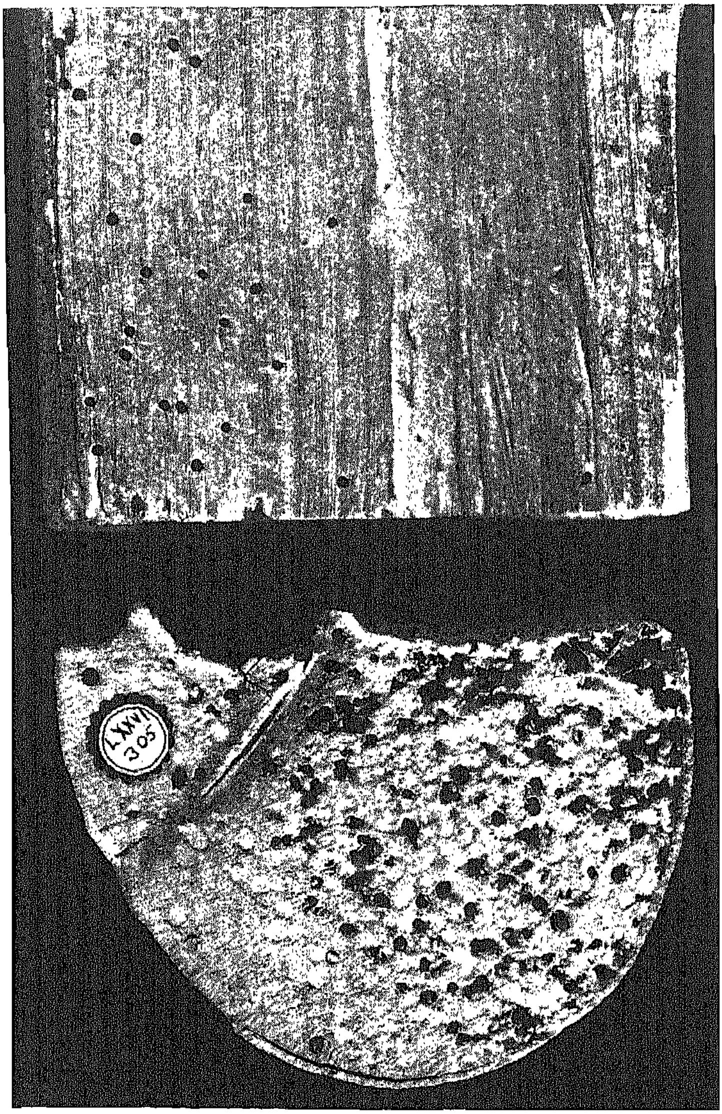


Fig. 111. Work of *Scobicia declivis* (Lec.) in fig wood. Upper figure shows emergence holes of adults; lower figure, the larval burrows.

almost impossible to get for ornamental purposes. The work of the larvae is most thorough, as is shown by figure 111. This beetle also has a peculiar habit, shared with a number of its relatives, of attacking lead cables and similar articles while under the stimulation of hot weather. The beetles bore through the lead to the inner lining, and thus cause a considerable loss of power when the cables later become wet. The Bostrichidae, as a whole, while destructive to wood products, are, however, not nearly so important economically as are the members of the family previously discussed or the one which will follow since they rarely breed in the same material for longer than a few generations, whereas the others generally breed as long as the wood will furnish food for their larvae.

THE TRUE POWDER-POST BEETLES, FAMILY LYCTIDAE

This family is a small one, containing but a limited number of species. The beetles themselves are also small, averaging less than the fifth part of an inch in length, and are fairly linear, as shown in figure 110*b*. From the members of the other families they are readily distinguished by their general size and form, by the short antennae with definite club, and the much elongated first ventral segment. These insects will breed in the wood of a great number of broad-leaved trees, but have a preference for the hardwoods like ash, hickory, and oak. An oriental species also breeds commonly in the inner layer of bamboo. The infestation in wood generally takes place while the timber is being seasoned, especially in the yards or warehouses of the hardwood lumber companies.

The beetles breed like the death watches generation after generation in the same timber, finally reducing most of the interior to a pulverized condition, as shown in the oak flooring portrayed in figure 112. The adults mature in spring or early summer and eat their way to liberty, producing by so doing the characteristic shot holes seen in the panel to the left in the figure. In most cases, after mating the females go back into the same wood, or they may enter and start a colony in new lumber. As the boring is done almost entirely by the larvae or grubs, and in the interior of the lumber, the presence of these insects may not, as also in the case of termites, be made known until the woodwork breaks down and exposes the interior. When, however, one notices the shot holes in any article made of oak, ash, or hickory, he should become suspicious.

These beetles are indeed very destructive and, after the termites themselves, are the most injurious of all insects to seasoned wood products. They infest to a great extent the ash timbers which go into shipbuilding and wagon making, also the hickory which furnishes the handles to axes, spades, and similar tools, as well as the spokes to vehicles, and the oak which goes into floorings, furniture, and the like.

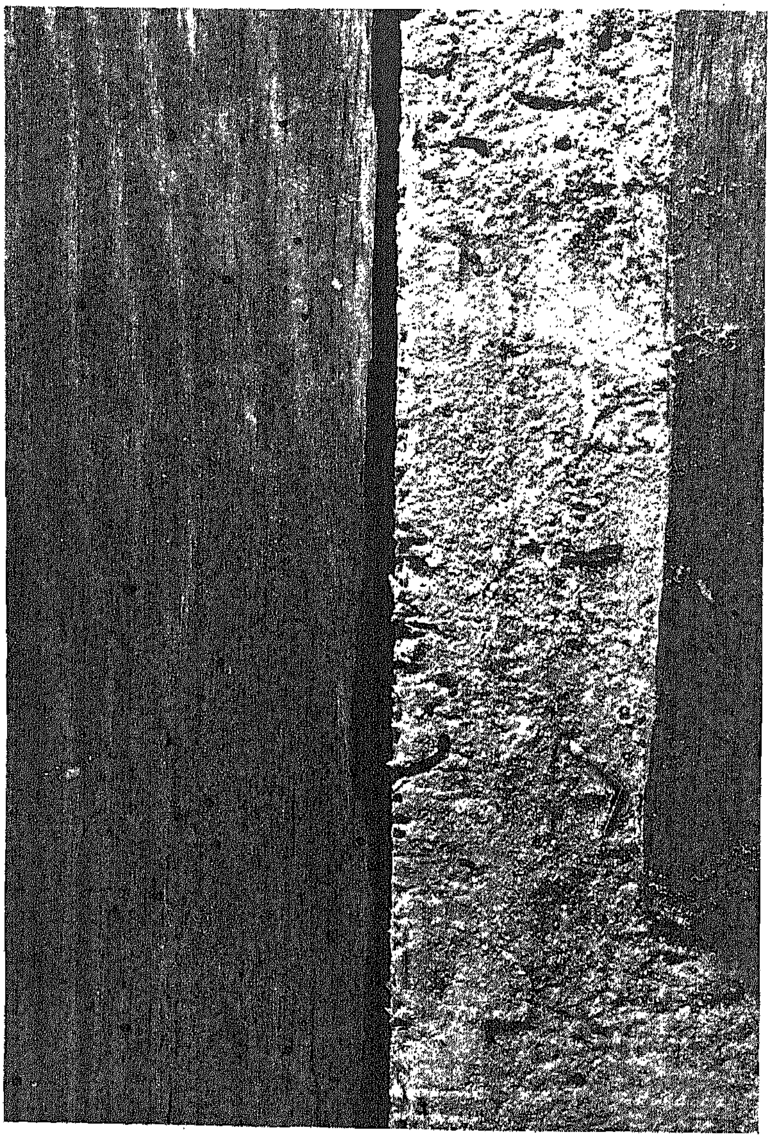


Fig. 112. Work of *Lyctus cavicollis,* a typical powder-post beetle, in oak flooring. Left, surface showing adult emergence holes. Right, work of larvae exposed by removing surface layer.

METHODS OF TREATMENT

As far as treatment is concerned, it is about the same for all the group mentioned above. Prevention is most important. Freshly cut lumber should not be stored in warehouses near lumber which has remained for years in the same place. It is the sapwood in most cases where the insects breed or, at least, first establish themselves. The sapwood of lumber imported for the arts or for interior household use should always be most carefully inspected before being finished. When damage is discovered in woodwork, the infested portion of the wood should be removed, destroyed, and replaced with sound material, to guard against the infestation of adjacent woodwork. When slightly infested material is discovered, it may be rid of its infestation by being kiln-dried. Thorough swabbing with kerosene repeated at intervals if signs of activity are noted will usually eliminate attacks in floor boards (Snyder, 1926*d*). Large supporting timbers may be creosoted and smaller, more valuable articles, such as furniture, be treated with hydrocyanide gas, preferably in retorts where a vacuum can be produced before the gas is allowed to enter. In England, valuable articles of bric-a-brac, when infested, are often soaked in turpentine or kerosene and thus saved.

As stated previously, the work of these various insects and their degree of destructiveness often leads to their being confused with the termites. When, however, the insects themselves are examined or the definite peculiarities of their workmanship noted, they may be readily distinguished.

PART II

CHEMICAL INVESTIGATIONS

INTRODUCTION

CHEMICAL INVESTIGATIONS made by the Committee have been directed along two lines: the prevention of termite attack on cellulose-containing substances, and the elimination of existing termite infestations. The preventive measures investigated were the effects of chemical and other preservatives applied to wood, the effects of paint films, and the effects of ground treatments with poisons. In the field of elimination of infestation, dust treatments and fumigation were investigated.

It was necessary to develop, by experimentation, the reactions of termites to many substances, solid, liquid, and gaseous, before information of practical value could be obtained. Afterwards, the results of these experiments were applied in the field, and tentative conclusions as to their success were drawn. The time available for investigations, three years, did not warrant the initiation of many service tests of methods or materials, but a few such tests were started. Various cooperative tests with individuals or organizations interested in the termite problem were undertaken.

Owing to the similarities between the problem of wood decay and that of termite damage, many of our investigations consisted of checking the reactions of termites to the toxicity, repellence, etc., of chemicals or preservatives which have long been used to prevent wood decay.

Actual application in every-day service over a long period of time will be required to prove the value of chemicals in the termite problem. The data presented herewith should, however, afford fundamental information of considerable value.

Chapter 33

THE TOXICITY OF CHEMICALS TO TERMITES

BY

MERLE RANDALL, W. B. HERMS, AND THOMAS C. DOODY

Reports on past tests show that the value of a chemical in protecting wood from termite damage can be ascertained only after several years of exposure. Most such experiments in test yards heavily infested with termites have been continued for periods of from three to twenty years. The early indications of the value of preservatives after a year or two of exposure have often been reversed as the tests were extended over a period of years. The Termite Investigations Committee soon realized that field tests of many treatments could not be concluded within its three-year program.

One of the most pressing problems in the early stages of the investigation was the consideration of remedial or control treatments of structures infested with termites. The literature on termite control showed a great number of substances recommended for application to infested materials. All of these remedial treatments could not be tested in the field, so it was planned to select only the most promising for extensive practical tests.

Small scale laboratory tests had already proved an inexpensive and effective method of comparing the values of fumigants in termite control. Results were usually obtained within a few hours, so it was not necessary to develop a technique for keeping the termites alive over extended periods. More difficulty was encountered in testing the toxicities of proposed remedial treatments, as some of them showed practically no effect on the insects. The value of such tests obviously depended upon the possibility of keeping the termites alive long enough to prove the ineffectiveness of such chemicals as are but slightly toxic.

Preliminary Toxicity Tests

The first laboratory toxicity tests were carried on with the three species of termites most abundant on the Pacific Coast. The damp-wood termite, *Zootermopsis angusticollis,* is probably the hardiest and most easily handled species. It is kept best in a very damp atmosphere or with a few drops of water present, which is somewhat of a disadvantage when chemicals which tend to absorb water are under test. The dry-wood termite, *Kalotermes minor,* is also quite easily kept, but is not nearly so hardy as the first mentioned species. If kept in a warm place with a slightly humid atmosphere, it does very well. The dry-wood termite was not used extensively in the first tests, as it is not abundant in the San Francisco Bay area. The subterranean termite, *Reticuli-*

termes hesperus, is most common in this region, but it is the most difficult to care for and control in the laboratory. It requires carefully controlled moisture conditions, and is highly susceptible to extermination by growths of molds or fungi. Due to the difficulty of keeping this species in small groups, it was used only in these first tests. The effects of any one chemical on the three species of termites, although not identical, were found comparable, so the hardier species only were used in later experiments.

TABLE 27

PRELIMINARY TESTS ON TOXICITY OF CHEMICALS

	Per cent preservative by weight	Time (hours) required for 100 per cent kill		
		Reticulitermes hesperus	*Kalotermes minor*	*Zootermopsis angusticollis*
Untreated paper	....	400	1,000+	Live indefinitely
Arsenic:				
White arsenic (As_2O_3) dust	....	16	88–	
Paris green dust	....	16	47–	
Sodium arsenite dust	....	3	....	
Sodium arsenite caked dust	....	24	....	
Sodium arsenite paper soaked in 10% solution	....	57	145	
Barium carbonate dust	....	310	....	
Barium chloride (paper soaked in 15% solution)	....	343	....	
Borax (paper soaked in 5% solution)	....	90	....	
Boric acid (paper soaked in 5% solution)	....	90	....	
Calcium arsenate dust	....	29	24	
Copper sulfate (paper soaked in 30% $CuSO_4.5\ H_2O$ solution)	29.5	430	....	270+
Copper sulfate (paper soaked in 15% solution)	11.6	....	480+	770+
Lime (air slaked) powder	....	600	....	
Mercurous chloride (calomel) dust	....	96	116–	
Mercuric chloride (paper soaked in 6% solution)	8.3	24	46	33
Sodium arsenite dust	....	3	....	
Sodium chloride (salt) dust	....	30	480+	
Sodium chloride (paper soaked in 15% solution)	....	128	....	
Sodium carbonate dust	....	91	....	
Sodium fluoride (paper soaked in 3% solution)	....	107	....	
Sodium fluosilicate (paper soaked in 2% solution)	....	23	....	
Sodium fluosilicate dust	....	49	106–	
Sugar (sucrose) granular	....	385+	....	
Zinc chloride (paper soaked in 10% solution)	17.0	228	....	

This first series of toxicity tests was not run under a specific testing routine, as the technique of caring for the insects was still experimental. From ten to fifty insects, either nymphs or workers, were used for each test group. The insects were kept in Petri dishes with filter paper for food; where water was necessary it was kept in a very shallow moisture cup with a screen cover. Wherever possible the chemicals were tested in several forms. The water-soluble chemicals were tested by soaking the filter paper, supplied as food, in solutions of the chemical and drying it before testing. Chemicals for which no suitable solvent was found were usually tested as dusts or powders. These first toxicity tests were only approximate, but they were of much value in the economical direction of suitable field tests. The results are given in Table 27.

The results of more exact laboratory tests of the toxicities of fumigants, dust poisons, paints, and proprietary wood preservatives will be found in the chapters devoted to these subjects. It was planned to repeat all the tests of Table 27 in a more exact routine manner. As this program was never completed, the rough values in the above table are the only data available on the toxicities of some of these materials.

STANDARDIZATION OF TOXICITY TESTS

The long time required to obtain significant results in practical tests of preventive treatments, when made on a field scale, and the costs involved in the installation of large numbers of such tests, made impossible such an undertaking by the Committee. Our first laboratory tests proved very useful and showed that a large number of materials could be investigated inexpensively and in a comparatively short time. Toxicity to termites is one of the most important requirements of a chemical treatment designed to prevent termite damage, but it is not the only factor, as discussed under the results of the standard toxicity tests. It was believed that a comparison of the toxicity to termites of various chemicals would prove to be a valuable guide for the testing and developing of termite-proofing materials, and that a standard laboratory test would give an inexpensive and ready method of obtaining preliminary indications of the values of commercial treatments.

The wood-preserving industry has long used laboratory toxicity tests with fungi for the preliminary testing of preservatives. The tests most used are standard in form, so that each investigator has a ready basis for the comparison of his tests with those of previous workers. A survey of the literature showed most of the work done in this connection with termites to be in the nature of small scale field tests. Little use had been made of laboratory tests with termites for the evaluation of chemical treatments. Some preliminary laboratory work with extractives from termite-resistant woods, oils, and commercial treatments had been carried on. There were no reports of a systematic attempt to study the toxicities of chemicals and preservatives as such on a laboratory scale, and there had been no proposal for a standardized routine laboratory test to determine the toxicities of substances to termites. Our early experience had already proved the value of such tests, so this seemed an opportunity for the Termite Investigations Committee to make an important contribution to the knowledge and development of termite-proofing materials.

The varied experimental conditions of the preliminary toxicity tests and the difficulties encountered in the satisfactory care of termites under laboratory conditions gave an excellent background for the development of a standard laboratory routine for such tests.

STANDARD TOXICITY TESTS

Choice of test conditions.—The choice of a test material was governed by an attempt to supply sufficiently natural conditions to permit survival of the termites during the laboratory test, and to afford ease of handling. Since

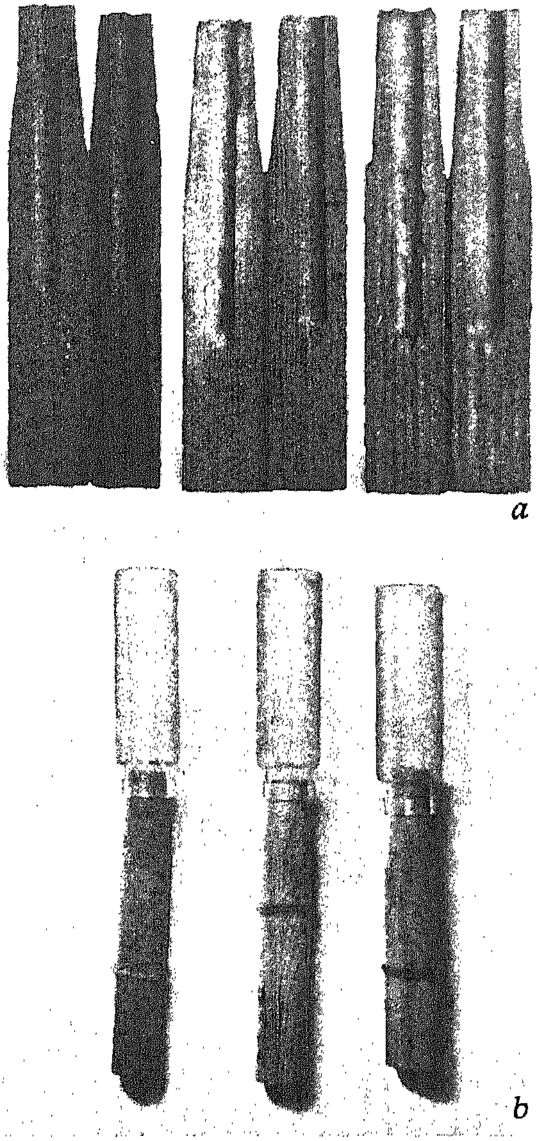


Fig. 113. Laboratory toxicity test. *a*. Tapered dowels of sapwood of redwood, Douglas fir, and sugar pine, in which dry-wood termites, *Kalotermes minor*, had lived for two weeks. Note that in this short time the termites had excavated wood at the end and sides of the artificial gallery. *b*. Dowels with vials in place as in a test. The termites readily entered the blocks from the vials.

the food of termites is preëminently cellulose, and the greatest damage caused by them is to wood and wood products, the natural choice for a test material was wood. To eliminate any possible effect upon the tests by an unexpected result from one particular species, three species of wood were used throughout. Sugar pine was used, as it was found in preliminary tests to be one of the most suitable woods in which to maintain laboratory colonies of the drywood termites, *Kalotermes minor,* and because it takes chemical treatment easily. Douglas fir, although more difficult to treat, was chosen because it is one of the woods most used structurally on the Pacific Coast. Redwood, another common wood on the Pacific Coast, was used because it was reputed to be naturally somewhat resistant, and because little was known about its treatment with preservatives.

The test blocks chosen had to be small so they could be completely and evenly penetrated by the preservative treatment. The shape of the test cell had to be adapted to the normal habits of the species of termites used. The blocks had to be constructed so as to make observations of the conditions in them easy, and not to interfere with the normal activities of the termites.

The test block chosen was a wooden dowel ½ inch (1.25 cm.) in diameter and 3 inches (7.6 cm.) in length, and divided down the center. The cells were actually made by facing together two 3-inch (7.6 cm.) pieces of ½-inch (1.25 cm.) half round stock. These ½-inch (1.25 cm.) dowels were tapered on one end so as to fit as a stopper into small glass vials. A hole $^3/_{16}$ inch (0.5 cm.) in diameter was made up the center of the dowel at the tapered end, extending about half the length of the dowel (fig. 113). Both halves of every dowel were numbered for identification and the two sections were held together by a small rubber band.

Treatments.—The chemicals were applied in solution to the test dowels by pressure impregnation treatment. A thorough saturation of the dowel with the treating solution was attempted in each treatment, and the retention of preservative was regulated by changing the strength of the treating solution. The so-called proprietary preservative test treatments were done differently, usually according to the manufacturer's recommendations, and are discussed separately in chapter 34.

The laboratory-scale treating plant is illustrated schematically in figure 114.[1]

Preliminary test treatments were made with creosote and crude petroleum oil on ½-inch (1.25 cm.) half round pieces of Douglas fir, redwood, and sugar pine 3 inches (7.6 cm.) in length, to determine the penetration of the preservative and to select a standard time of treatment. All these test pieces were of heartwood, as were the majority of the test dowels to be treated. The treatments were made with the preservatives at 180° F. (82° C.) and at a pressure of 100 pounds per square inch (7 kg./sq. cm.). The sugar pine blocks were completely penetrated by these oils in 15 minutes or less. The redwood took treatment almost as readily, these very small pieces being thoroughly treated in 20 minutes. The Douglas fir heartwood, however, was very difficult to treat. A series of test blocks in which the treating period ranged from 10 minutes to 36 hours showed a marked increase in retention of preservative in treating periods of up to 35 to 40 minutes. Very little improvement over the 40-minute treatment was shown in the 24- and 36-hour periods, which still did not show complete saturation with the preservative in every case. Treatments with aqueous solutions and lighter solvents were found to penetrate

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[1] We wish to acknowledge the courtesy of the Curtin-Howe Corporation in putting the services of Mr. C. H. Watson at our disposal to cooperate in the construction of, and preliminary experiments with, the laboratory treating chamber.

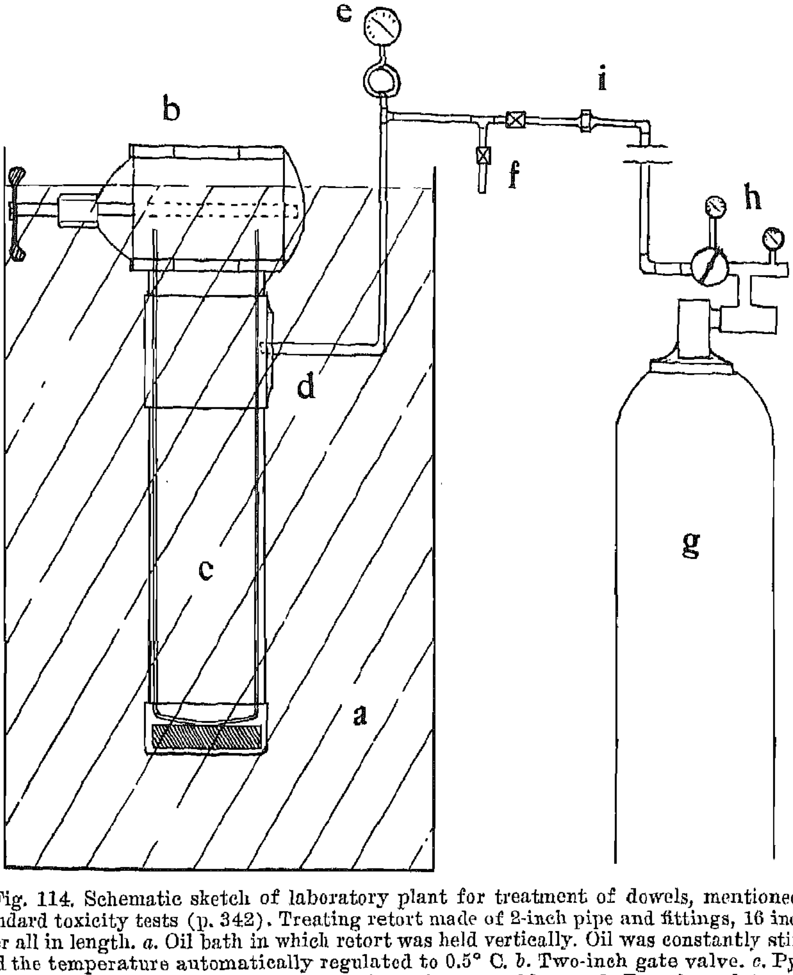

Fig. 114. Schematic sketch of laboratory plant for treatment of dowels, mentioned in standard toxicity tests (p. 342). Treating retort made of 2-inch pipe and fittings, 16 inches over all in length. *a*. Oil bath in which retort was held vertically. Oil was constantly stirred and the temperature automatically regulated to 0.5° C. *b*. Two-inch gate valve. *c*. Pyrex glass tube, loosely fitted into retort and resting on rubber pad. Dowels and treating solution were placed in this tube through gate valve. *d*. Three-eighths inch pipe extending from two reducing tees, which made up the central portion of the retort, to a compressed air cylinder, *g*, which supplied air. *e*. Pressure gauge and *f*, valve system, controlled air pressure. *h*. Diagram type reducing valve. *i*. Union in the pipe line allowed ready replacement of fresh air cylinders.

somewhat more easily, and accordingly a 45-minute treating period was adopted as standard. The treatments with aqueous solutions and with heavy oils were all done at 180° F. (82° C.). Where it was necessary to use a volatile or inflammable solvent, such as benzol or petroleum ether, the treatments were done at room temperature of 70°–90° F. (20.6°–32° C.).

Nine test dowels, three in each of the test wood species, were treated with each concentration of the chemical to be tested. The dowels were all of well dried, air-seasoned heartwood. Each group of three dowels was weighed before treatment. After treatment the dowels were allowed to air-dry for two or three months and again weighed. The average retention of preservative for the three dowels was computed from the difference in the final weights before and after treatment. This procedure was adopted in spite of the variations in moisture content of the dried dowels at the times of weighing. The weighing of the dowels immediately after treatment, to determine the retention of chemical from the increase in weight and the known strength of solution, was abandoned, because of rapid changes in weight where volatile solvents were used. This method would probably have given more exact results with the aqueous solutions, but it is believed that the method used gave errors of less than 5 per cent.

TABLE 28

FRACTIONS OF WOOD DISSOLVED BY VARIOUS SOLVENTS

Solvent	Douglas fir	Redwood	Sugar pine
	per cent	*per cent*	*per cent*
Hot water	0.52	1.08	1.91
Alcohol	3.13	3.88	1.14
Petroleum other	3 60	4.47	2.66

In treatments with very dilute solutions a loss of weight was found after treatment. This necessitated tests on each species of wood to determine what weights of resins and other substances were dissolved by each solvent under the conditions of treatment. Corrections for the weight of material dissolved from the wood were applied throughout the computations of retention of preservative. Often the results obtained for retention of preservative in treatments with dilute solutions were still aberrant. In such cases the retention of preservative was estimated by proportion from the more reliable figures obtained in treatments with concentrated solutions. Estimates thus arrived at are marked by an asterisk (*) in the table of results.

The weights of the materials dissolved from the woods were surprisingly large. This factor may in part account for the peculiar results sometimes obtained for the retentions of preservatives in small scale experimental treatments and in commercial wood preservation. Some of the more important results are given in Table 28, the figures expressing the per cent of the original weight of the wood removed by the solvent.

Testing of toxicity.—Ten full grown nymphs of *Kalotermes minor*, recently removed from their burrows, were placed in a small glass vial, and the test dowel set in the vial as a stopper. The dowel was set vertically in a rack, with the vial up, so the termites would fall onto the dowel. The test was kept in the light throughout its progress. Due to the desire of the insects to keep out of the light (negative phototropism), all of them left the glass vial and entered the hole in the center of the test dowel within a few minutes. Tests left in the dark showed continual migration of the insects between dowel and vial. Furthermore, in tests kept in the dark, the termites soon bored through the wood of the dowel and either wandered from one dowel to another or were lost completely. This did not occur when the dowels were kept in the rack in the light. Thus the termites could be forced to stay in the dowel in which they had been placed and the mixture of tests was avoided.

All the dowels of one concentration of preservative were started at one time, with one additional test dowel of each of the untreated woods as control. There were three treated and one untreated dowel of each wood, or twelve dowels in each test group. The untreated, or control, dowels gave opportunity to observe the termite under the conditions of the test but in the absence of the chemical under test, and furnished a base line of zero toxicity for comparison of the chemical treatment.

Observations on the death rate of the test insects were made according to a definite schedule, so arranged that the maximum probable error in the life periods was not more than 10 per cent of the recorded value. This specified schedule of observations was as follows: every day for the first week; every second day during the second and third weeks; every third day during the fourth, fifth, and sixth weeks; and once a week after the sixth week, until the end of the test.

At each observation the number of insects still alive was recorded. Often the insects had burrowed into the test dowel, so that part of the wood had to be cut away and the insects removed in order to make certain of their condition. The figures given in the toxicity table (p. 350) represent the averages of the survival periods for the insects in each set of three identically treated test dowels of each species of wood.

The termites in the untreated control dowels were often noticeably affected when run in connection with test groups in which the preservative was somewhat volatile. Also, in some of the tests on extremely poisonous preservatives, the results in the individual controls were not in accord with the average of the controls. This deviation was probably due to accidental poisoning in handling. The average findings on the survival periods for the insects in the control dowels were quite uniform. The results for the numerous untreated dowels run in connection with zinc chloride, which was tested in fourteen concentrations, are shown in figure 115. This represents the average results of fourteen dowels of each species of wood, and because of the uniformity of the results on untreated dowels these figures have been used as the standard of zero toxicity. The natural survival period of the insects is much shortened by handling them in making the frequent required observations, but this factor does not affect the results, as it is uniform throughout the tests.

The curves (fig. 115) for the death rates of the termites in the untreated wood dowels show clearly the reason for selecting the time at which 80 per cent of the termites were dead as a comparison point for toxicity. The curves for all three species of wood are practically straight lines until more than 80 per cent of the insects are dead. This allows a reasonably exact figure to be selected from the curves for the number of days at which 80 per cent of the termites will be dead if there is no toxic effect. The 100 per cent death point for zero toxicity cannot be definitely stated, as a few unusually hardy insects in a series of tests live on indefinitely and the actual condition of 100 per cent death is not reached. The values used in the toxicity table were obtained by extrapolating the curves to 100 per cent death. These values are so uncertain that it is best to state the time as more than (>) a given number of days. This does not hinder the use of the 100 per cent death point for comparison if the chemical treatments show a noticeable toxicity.

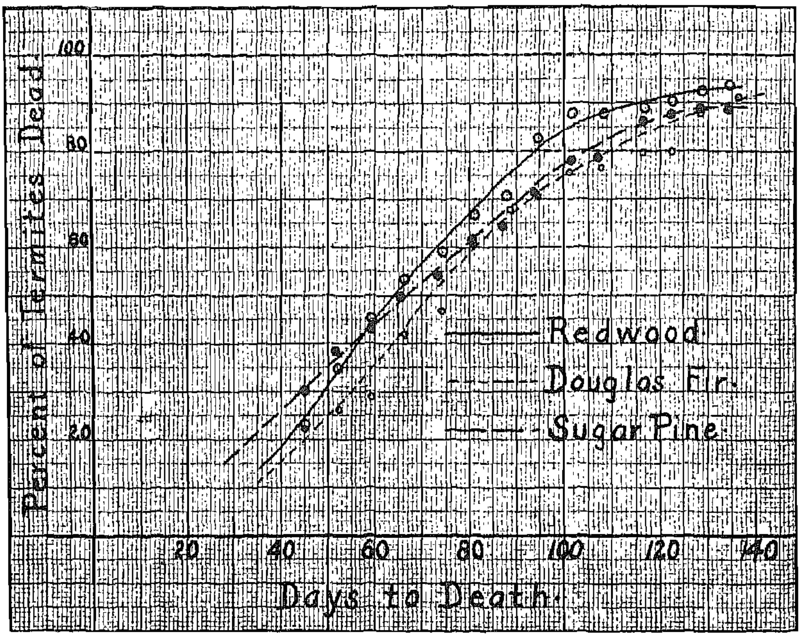

Fig. 115. Actual and average death rate of termites in untreated dowels of redwood, Douglas fir, and sugar pine, based on fourteen dowels of each species of wood. These dowels were placed under test in connection with toxicity tests on chemicals.

These curves also show a small but notable toxic effect in untreated redwood as compared with other species of wood used in the tests. A commercial grade of redwood, designated "heart common," was used. The rate of death of the insects in the untreated redwood is somewhat greater than in the other two species. The comparison at the 80 per cent death point is as follows: redwood, 94 days; Douglas fir, 110 days; sugar pine, 105 days. Tests of the termite-resistivity of these three species of wood show a different relation between species of termites, however (chap. 41).

Results of tests.—The results of the toxicity tests are given in tabular form in Table 29. In the first column are given the name of the chemical and the strength of the treating solution in per cent by weight. The solvent used for the treating solution has always been hot water, unless otherwise specified. Complete data for the three test woods are given. The average weight of treatment in each group of test dowels is expressed in two ways: per cent by weight of the chemical (based on the final weight of the treated dowels), and as pounds of chemical per cubic foot of wood. The retention of preservative in commercial treatments is always expressed as pounds of preservative per cubic foot of wood, but this is not exactly comparable with the figures given under the same name for the treated dowels. According to commercial practice, the figure for pounds of preservative per cubic foot of wood is based on the entire volume of the wood subjected to treatment. One pound per cubic foot equals 16.02 kilograms per cubic meter. Only an exterior shell of the treated wood is thoroughly penetrated by the preservative, leaving the interior of the timber untreated. The commercial figure of "pounds per cubic foot" is consequently lower than that for the same treatment figured on the basis of "pounds of preservative per cubic foot of completely penetrated wood." It is this last figure which is given for the dowels, which were completely penetrated by the preservative treatment. For comparison of the toxicities of the materials tested, figures are given in days required to kill 80 per cent of the termites, and days required to kill 100 per cent. Where the tests were discontinued before all the termites were dead the results for days required for 100 per cent kill are given as more than a certain number.

Similar standard tests of toxicity were made on several commercial wood preservatives and proprietary treating materials made for home application. Tables presenting the results of these tests will be found in chapter 34.

Discussion.—Each chemical treatment was tested in a series of concentrations to obtain some basis for judging the minimum amount of preservative which is toxic to termites. Those materials which have been used for termite control, and others which seemed of importance, were tested at several concentrations so as to cover the complete usable range of dilutions. The figures in the table denoting the toxic power of some concentrations are quite irregular, but the general trends in toxic power are evident for each of the series. The results of these tests show surprising exactness for experiments subject to the peculiarities of behavior of living insects.

In general, toxicity is expected to increase with concentration, but this expectation is not always realized, because the response of termites to toxic agents varies with changes in concentration. Heavy concentrations may repel and restrict eating. One of the most striking contrasts in the toxic results obtained as compared with the concentration of the chemical used is shown in the case of sodium arsenate. Here it appears that the less chemical used in the wood the more toxic the treated wood becomes. There is no evidence or conclusive reason for believing this to be true, although in general the toxicity

TABLE 29

DATA ON TOXICITY OF CHEMICALS

Preservative	Douglas fir				Redwood				Sugar pine			
	Per cent preservative	Pounds per cubic foot	Days to kill 80 per cent	Days to kill 100 per cent	Per cent preservative	Pounds per cubic foot	Days to kill 80 per cent	Days to kill 100 per cent	Per cent preservative	Pounds per cubic foot	Days to kill 80 per cent	Days to kill 100 per cent
Untreated controls	....	....	110	>170	....	....	94	>160	....	....	105	>170
Aloes .16% in water	0.18*	0.07*	112	>160	0.22*	0.07*	86	>160	0.24*	0.09*	110	>160
Arsenious acid 2%	1.99*	0.753*	7	11	2.56	0.737	8	11	1.68	0.607	8	12
1%	0.99*	0.38*	11	14	1.28	0.368	12	18	0.84	0.30	12	14
.25%	0.25	0.095	18	26	0.32	0.092	19	26	0.21	0.076	18	28
.1%	0.099*	0.038*	23	35	0.128	0.037	33	40	0.084	0.030	19	40
.05%	0.049*	0.019*	41	63	0.064	0.018	27	55	0.042	0.015	35	48
.025%	0.025*	0.0095*	57	84	0.032	0.0092	49	61	0.021	0.0076	46	62
.01%	0.0099*	0.0038*	56	84	0.0128	0.0037	49	88	0.0084	0.0030	56	85
.005%	0.0049*	0.0019*	46	116	0.0064	0.0018	91	123	0.0042	0.0015	68	114
.0025%	0.0025*	0.00095*	67	161	0.0032	0.00092	50	84	0.0031	0.00076	90	151
.001%	0.00099*	0.00038*	113	160	0.00128	0.00037	85	144	0.00084	0.00030	88	141
Barium fluosilicate (saturated solution)	0.10*	0.027*	13	18	0.12*	0.033*	14	18	0.18*	0.047*	11	17
Beta naphthol 10% in alcohol	10.8	3.6	5	8	13.4	3.7	6	8	13.9	4.1	6	7
5%	5.4*	1.8*	7	13	6.7	1.85	23	43	6.95	2.05	34	56
1%	1.1*	0.36*	76	>156	1.34	0.37	67	>156	1.39	0.41	98	>156
.5%	0.55*	0.18*	>156	......	0.67	0.18	>156	....	0.69	0.20	>156	....
.1%	0.11*	0.036*	93	>156	0.13	0.037	>156	....	0.14	0.041	>156	....
Creosote†												
Cryolite (saturated solution)	0.08*	0.022*	22	38	0.11*	0.030*	32	61	0.13*	0.035*	23	33
Cupric sulfate 50%	19.24	9.42	25	36	28.63	10.00	26	33	32.90	12.98	24	36
25%	9.62*	4.71*	30	42	14.32	5.00	31	42	16.45	6.49	24	36
15%	6.41*	3.14*	46	84	9.46	3.33	48	77	10.12	4.32	35	47
10%	3.86*	1.88*	56	106	5.72	2.00	99	157	6.58	2.49	85	116
5%	1.924*	0.94*	51	90	2.86	1.00	76	125	3.29	1.30	78	204
1%	0.386*	0.188*	66	>190	0.572	0.20	127	160	0.658	0.249	120	......

* Figures computed.

† See Table 29A, chapter 34.

TABLE 29—*(Continued)*

Preservative	Douglas fir				Redwood				Sugar pine			
	Per cent preservative	Pounds per cubic foot	Days to kill 80 per cent	Days to kill 100 per cent	Per cent preservative	Pounds per cubic foot	Days to kill 80 per cent	Days to kill 100 per cent	Per cent preservative	Pounds per cubic foot	Days to kill 80 per cent	Days to kill 100 per cent
Untreated controls	....	....	110	>170	....	....	94	>160	....	....	105	>170
Magnesium fluosilicate 5%	4.87*	1.60*	10	14	6.25	1.64	9	16	5.0	1.65	17	25
2%	1.94*	0.64*	8	21	2.50	0.65	12	17	2.0	0.66	17	29
1%	0.97*	0.32	24	40	1.25	0.328	24	59	10.0	0.331	26	34
.25%	0.3*	0.080*	49	79	0.31	0.082	24	49	0.25	0.083	17	25
Magnesium sulfate 30%	24.7	10.3	56	144	29.9	8.6	89	>150	12.5	4.8	72	142
10%	7.87	2.52	86	254	9.43	3.09	102	205	7.93	2.25	212	>254
5%	3.66	1.08	145	>254	3.51	0.83	176	>254	3.43	1.03	114	>254
2%	1.65*	0.69*	170	254	2.0	0.57	137	214	1.58	0.45	88	152
Manganese sulfate 20%	23.0	8.8	33	44	27.2	8.7	39	60	29.8	11.0	22	33
10%	13.6	4.97	45	106	14.5	4.26	42	85	15.4	5 2	54	104
5%	6.75	2.15	63	116	7.06	1.72	30	59	8.41	2.45	28	83
Mercuric chloride 5%	5.97	2.38	4	7	5.78	1.57	5	7	7.07	2.00	3	5
1%	1.196*	0.476*	19	30	1.16*	3.14*	18	31	1.41*	0.40*	25	49
.5%	0.597*	0.238	24	37	0.578*	0.157	19	41	0.707*	0.20	29	54
.1%	0 120*	0.048*	21	45	0.116*	0.0314*	30	59	0.141*	0.040*	52	83
.05%	0 0597*	0.0238*	28	63	0.0578*	0.0157*	21	55	0.0707*	0.020*	45	73
.01%	0.012*	0.0048*	44	58	0.0116*	0.00314*	61	85	0.0141*	0.0040*	38	83
Nicotine sulfate 4%	8.47	2.65	12	31	11.6	3.01	20	30	8.15	2.28	16	33
2%	4.75	1.50	32	164	6.33	1.55	18	34	6.60	1.92	40	79
.8%	1.69*	0.53*	48	63	2.32	0.60	63	97	1.63	0.45	88	132
.4%	0.846*	.....	40	86	1.16	0.301	34	60	0.815	0.228	42	96
.2%	0.42*	0.13*	118	162	0.58	0.15	55	84	0.41	0.13	97	134
Potassium xanthate												
in hot alcohol 10%	9.67	2.90	77	>110	14.2	3.4	83	116	12.8	3.90	69	133
in hot alcohol 5%	4.83*	1.45*	96	165	7.10*	1.70*	105	>165	6.4*	1.95*	79	>165
in hot alcohol 1%	0.97*	0.29*	119	>165	1.42	0.34	117	>165	1.28	0.39	156	>165
in cold water 10%	6.44	1.98	98	>165	9.18	2.25	75	>165	9 57	3.06	125	>165
in cold water 5%	3.32*	0.99*	164	>165	4.59	1.13	66	>165	4.79	1.53	92	>165
in cold water 1%	0.64*	0.20*	164	>165	0.92	0.23	109	>165	.96	0 31	165	>165

* Figures computed.

TABLE 29—*(Continued)*

Preservative	Douglas fir				Redwood				Sugar pine			
	Per cent preservative	Pounds per cubic foot	Days to kill 80 per cent	Days to kill 100 per cent	Per cent preservative	Pounds per cubic foot	Days to kill 80 per cent	Days to kill 100 per cent	Per cent preservative	Pounds per cubic foot	Days to kill 80 per cent	Days to kill 100 per cent
Untreated controls	....	....	110	>170	....	....	94	>160	....	....	105	>170
Quassia chips, 5 pounds in 50 gallons water	0.60*	0.16*	81	>156	0.78*	0 20*	105	>156	0.86*	0.28*	82	>156
Sodium arsenate 10%	....	....	>103	>165	....	....	>122	>156	....	....	116	>140
1%	....	....	>134	>200	....	....	102	>176	....	....	134	>180
.1%	....	....	>170	>191	....	....	110	>191	....	....	104	>177
.01%	....	....	74	132	....	....	31	123	....	....	141	>196
.005%	....	....	21	83	....	....	45	94	....	....	34	52
.001%	....	....	33	47	....	....	16	26	....	....	27	35
Sodium arsenite 10%	19.12	8.70	1	5	24.73	8.40	2	4	23.54	7.82	2	3
1%	1.912*	0.87*	9	15	2 473	0.84	5	11	2.354	0.78	9	15
.1%	0.1912*	0.087*	29	53	0.2473	0.084	35	47	0.2354	0.078	33	48
.01%	0.019*	0.0087*	79	149	0.0247	0.0084	69	137	0.0235	0.0078	98	173
.005%	0.0095*	0.00435*	69	120	0.0124	0.0042	82	125	0.0168	0.0039	50	115
.001%	0.0019*	0.00087*	50	121	0.00247	0.00084	65	150	0.00235	0.00078	71	145
Sodium chloride 30%	24.6	10.4	33	48	34.0	10.7	26	35	28.3	10.6	38	56
10%	10.7	3.4	58	69	11.9	2.98	58	83	1.08	3.28	66	73
5%	4 90	1.58	62	70	6.28	1.65	66	98	5.50	1.55	72	92
Sodium dichromate 20%	19.9	7.53	28	49	25.6	7.37	25	57	16.8	6.07	23	42
10%	10.3	3.73	32	43	15.8	3.9	25	43	9.72	3.25	38	71
5%	5.3	1.70	22	36	7.94	1.82	41	46	4.02	1.25	51	72
2%	1.99*	0.75*	49	64	2.56	0.74	29	45	1.68	0.61	39	66
Sodium fluoride 4%	6.56	2.44	8	14	5.78	1.54	9	12	6.66	1.71	8	11
2%	3.28*	1.22*	15	22	2.89	0.752	14	19	3.33	0.850	15	21
1%	1.64*	0.61*	16	25	1.45*	0.376*	15	22	1.652*	0.425*	19	31
.5%	0.82*	0.305*	19	31	0.73	0.188	17	30	0.83	0.213	21	38
.25%	0.41	0.152	21	25	0.36	0.099	17	33	0.42	0.107	25	40
.1%	0.1604	0.061	58	104	0.141	0.0376	40	42	0.1606	0.043	71	128

* Figures computed.

Preservative	Douglas fir				Redwood				Sugar pine			
	Per cent preservative	Pounds per cubic foot	Days to kill 80 per cent	Days to kill 100 per cent	Per cent preservative	Pounds per cubic foot	Days to kill 80 per cent	Days to kill 100 per cent	Per cent preservative	Pounds per cubic foot	Days to kill 80 per cent	Days to kill 100 per cent
Untreated controls	....	....	110	>170	....	....	94	>160	....	....	105	>170
Sodium fluosilicate 2%	5.83	2.00	2	7	5.69	1.42	3	8	7.82	2.35	2	4
1.5%	4.38*	1.50*	8	15	4.26	1.08	5	11	5.85	1.77	11	15
1%	3.19	1.05	10	15	4.03	1.02	8	12	3.79	1.05	9	15
0.5%	1.46*	0.50*	11	19	1.42*	0.36*	16	23	1.95*	0.59*	19	29
Sodium hydroxide 5%	9.84	3.4	82	113	9.94	2.28	61	100	8.80	2.80	33	87
2%	2.02	0.72	83	180	2.97	0.72	112	201	3.72	1.10	84	123
1%	1.40	0.45	86	171	0.90	0.30	107	163	1.91	0.55	100	147
Sodium metasilicate 37%	......	......	44	59	......	......	40	53	......	......	44	53
Sodium orthophenyl phenate												
10% (hot water)	12.6	4.1	3	4	12.4	3.67	3	4	10.8	3.5	4	5
5%	6.67	2.00	11	22	8.38	2.08	10	17	8.37	2.43	10	28
1%	1.26*	0.41*	46	>170	1.24	0.37	38	63	1.08	0.35	79	>170
Sodium silicate												
$\frac{SiO_2}{Na_2O}=3.25$ (25° Be)	......	......	53	61	......	......	53	61	......	......	49	56
$\frac{SiO_2}{Na_2O}=2$ (35° Be)	......	......	42	53	......	......	49	61	......	......	44	51
Strychnine ½ oz. per liter acidified with HCl	0.33*	0.125	76	103	0.39*	0.123*	32	82	0.42	0.156	58	103
.1 oz. ditto	0.065*	0.0250*	>163	.....	0.077*	0.0246*	121	>163	0.085*	0.031*	96	163
025 oz. ditto	0.016*	0.0063*	93	>163	0.019*	0.0061*	>163	.....	0.021*	0.0078*	>163	.....
.016% in water	0.0184*	0.0070*	>165	.....	0.0218*	0.0069*	>165	.....	0.0238*	0.0088*	89	>165
.004% in water	0.0046*	0.00175*	>163	.....	0.0054*	0.00173*	46	>163	0.0059*	0.0022*	>163	.....
Sucrose 60%	38.6	18.6	59	68	50.9	30.7	58	73	46.3	24.7	53	77
30%	20.7	9.06	84	95	30.4	10.7	70	90	25.5	9.2	71	83
15%	11.6	3.5	65	86	13.9	3.4	76	104	12.4	3.8	57	73
White hellebore .9% in water	0.74*	0.20	64	>160	1.47	0.40	64	118	0.89	0.28	40	91
Zinc chloride†	......	......	......	.....	.....	......	.....	.....	......	......	.....	.....

* Figures computed.

† See section on Wood Preservatives, Table 29A, chapter 34.

of arsenites is known to be far greater than that of arsenates. The arsenite-arsenate equilibrium here may be a factor. The most conclusive point in favor of the correctness of this interpretation is that much more of the wood was eaten in the case of the dilute treatments.

Such variations in the results indicate clearly the necessity for basing toxicity figures on a system of statistical averages. Experiments which show discrepancies should be repeated again and again. The three years of investigation have left points which require further experimental verification. The results of our tests, conclusive or not, are presented to stimulate further investigation.

The results show the difficulty of stating a definite concentration for each chemical at which its toxicity becomes ineffective. The notably poisonous materials show a persistent toxic power even in extremely dilute solutions. Most of the chemicals usually considered as non-poisonous show a toxic effect on termites in high concentrations. Sometimes this effect disappears rapidly as the treating solution is diluted below a certain value. Computations on the results of several of the non-poisonous chemicals have shown the effect on the insects to be directly proportional to the concentration or number of molecules, or, more exactly, to the concentration of ions available from the treated wood. This leads one to believe that the toxic power of this type of material is due to its effect in changing the osmotic pressure in the termite's digestive system. This change in osmotic pressure would kill the intestinal Protozoa on which the insect depends for digestion of its food.

Materials of this *relatively* non-poisonous type, such as copper sulfate, sodium chloride, sucrose (cane sugar), and zinc chloride, have shown a much higher toxic power in these "standard toxicity tests" than in our first toxicity experiments. This is explained by the fact that water was always available to the termites in the first tests, so they were able to dilute the chemical treatment in their food. In the standard toxicity tests the insects had to eat the dry wood containing the chemical or starve, and had no opportunity to dilute the chemical. Observations on the use of copper sulfate, sodium chloride, and zinc chloride in the field have revealed a resistance to termite attack, but the treated materials could not be called "termite-proof." The field tests do not show an effectiveness quite so great as that indicated in the standard toxicity test, where the insects were unable to reduce the concentration of chemical.

The amount of treated wood eaten by the termites in each test dowel was an important and significant factor. It was found impossible to measure or record the amount eaten in each test, as wood had to be cut from the dowel at each inspection to keep the insects in view (but see chap. 44). These experiments were run primarily to test the toxicity of chemical treatments. Since detailed observations of the important factor of distastefulness of treated materials would have interfered with the original purpose of the test, only casual observations were made on the rate at which the treated wood was eaten. Dowels treated with copper sulfate and zinc chloride were eaten slowly, as compared to those treated with materials which did not show immediate toxic effects. Sodium chloride was also evidently distasteful. On the other hand, wood treated with potassium xanthate and strychnine was eaten to a greater extent than the average, while wood treated with sucrose was eaten very rapidly. The distastefulness of treated materials is certainly an important factor in preventing termite infestation under service conditions. This is one of the chief factors to which the successful service results with copper sulfate and zinc chloride are attributed.

Summary.—The results of these toxicity tests are of great importance in judging the possibilities of different chemical treatments for termite control. Factors other than toxicity should also be considered in interpreting the value of these tests. Toxicity may not be essential in order that a treatment prove adequately *termite-resistant* in practice. *Treated wood will be termite-proof only if the chemical or preservative used is toxic.* Then the termites, although they may be able to attack the wood, will be unable to exist in it or to damage it extensively. *Treated wood may be adequately termite-resistant if the preservative is sufficiently distasteful, or noxious, to termites to check infestation.* This type of preservative may give satisfactory protection from termite attack, but it is not termite-proof. If, in a building or any other structure all the wood products available to termites are treated, those materials having the least distasteful treatments will be more likely to be attacked. If the preservative is not toxic to termites and its protective power lies only in its distastefulness, termites will still be able to live in, and perhaps ultimately to destroy, the treated product.

The permanence of a preservative treatment is another important practical factor which was not tested in these laboratory investigations of toxicity. None of the materials considered in the above table has so transient an effect as to be considered a fumigant. Most of them are water-soluble, as is shown in the method of application of the treatments. The permanence of these materials when exposed to the elements can be judged best by their past use in the field and by practical field tests. Often the treated material is to be used where it will not be exposed to weathering, or where it can be satisfactorily protected by a coat of paint. An extensive series of laboratory leaching tests to compare the permanence of the chemical treatments was considered, but it was impossible to include these in our program.

The results of the toxicity tests reported above show many discrepancies and indicate unsolved toxicological problems which it is hoped may be solved by future tests.

PETROLEUM OILS

The first work with light petroleum greases, such as vaseline, showed them very effective in killing termites. This work was continued by Miss Andrew by tests on the effects of a series of fractions of petroleum oil on the dampwood termite, *Zootermopsis angusticollis.* Part of these tests were made by dipping the insects in the oil and observing the effects of the oil and the time required to kill. This method has been used also by M. Oshima (1919) in Formosa. In other tests the insects were placed on wood or paper freshly soaked in the oils.

The results of these tests showed an anesthesia for the volatile petroleum products, a very high toxic power for the light oils, and a decreasing toxic power with increasing gravity of the petroleum product. The heaviest crude oils, containing much asphalt, showed almost no toxic power. The effectiveness of the light oils is due to a clogging of the trachae, which suffocates the termites.

Observations on field tests with petroleum products fall in line with the laboratory observations. Petroleum distillates show high toxicity in the nature of anesthesia, but are not permanent enough for practical use. Light petroleum oils show good penetrating power and effectiveness. The heavy oils soon dry and show practically no protective value. The results of these field tests are discussed in the chapters on ground treatments and wood preservatives. A proper blending of petroleum oils shows considerable promise for termite control and certainly warrants further experiment. In any experiments of this nature the high inflammability of wood soaked with petroleum oil should be kept in mind.

CHAPTER 34

WOOD PRESERVATIVES AND PROTECTIVE TREATMENTS

BY

MERLE RANDALL and THOMAS C. DOODY

The primary requisites of a good wood preservative are toxicity, permanence, and freedom from damaging effects upon the wood. Other special requirements are often made of treated wood, such as the ability to accept and retain paint, low electrical conductivity, small fire hazard, and the ability to be shaped and worked with edged tools. There must also be no danger from the preservative to the health of workmen or to users of the material, and the weight of the timber must not be increased to the extent that handling costs become excessive. Paramount to all these technical factors of wood preservation is the economic side; above all, the treated wood must give a service which will eventually save the consumer money.

This practical aspect of the science of wood preservation forbids the acceptance of any preservative on its laboratory tests alone. One factor at a time can be observed in the laboratory, but the varied and severe conditions of actual use are required to prove the value of a wood preservative. A good wood preservative must show an economic advantage over a period of years of service. Treated wood must eventually show a saving in material or in replacement costs, or else the cost of preservative treatment is not justified.

Methods of treatment.—The period of effectiveness of a wood-preserving treatment depends upon the character of the preservative and the thoroughness and permanence of treatment. Contrary to popular belief, a preservative does not ordinarily penetrate very far into the interior of the wood. The sapwood absorbs the preservative much more readily than the heartwood. A complete penetration of the sapwood can usually be obtained by the use of highly penetrating preservatives, or by use of an effective pressure-treating process. Even under the most favorable conditions difficulty is encountered in obtaining much penetration of the heartwood. Except in species where most of the tree is sapwood, the preservative treatment of timber or poles provides only a shell or casing of wood saturated with preservative around interior wood which has received no treatment. The durability of the preserved timber or pole will depend in a large measure on the thickness of this treated shell.

There are several types of treatment varying from the *brush application,* with a retention of about ½ pound of preservative per cubic foot (8 kg./cu. m.) of wood, to the *full-cell pressure treatment,* where it is possible to obtain a retention of 20 or more pounds of preservative to the cubic foot (320 kg./cu.

m.) of the total timber treated. The type of treatment selected is usually governed by economic factors involving the cost of the preservative and the length of service to be expected from the treated wood.

Effectiveness of methods of treatment.—Field observations and service records on superficial and impregnation methods of treatment indicate the relative values of these treatments. These records have come principally from a study of poles treated with coal-tar creosote, or proprietary preservatives the base of which is creosote.

Brush treatments with coal-tar creosote were at one time used extensively on poles because of their cheapness. Three brush coats of the hot preservative were usually applied, allowing each to soak in thoroughly before the next application. Service records on this treatment show that on an average it extended the life of the poles from two to five years over untreated material.

The *open-tank method* of treatment, when carefully and properly applied, will usually show full penetration of the sapwood of poles by the preservative. The treatment is much slower than the modern pressure processes. It is well adapted to the butt-treatment of poles and is extensively used for that purpose. In the application of coal-tar creosote by this treatment the poles are set in a vat of the hot preservative held at 220° to 270°F. (104° to 132°C.) for 4 to 8 hours and then allowed to cool. The poles are usually in the preservative bath for a period of 16 to 24 hours. Where protection of the pole butt only is necessary, *i.e.*, protection from fungus or subterranean and damp-wood termites, the creosote open-tank treatment does not show a large per cent of failures before about 15 years. Cases where extensive failures have occurred in about 5 years have been traced to improper or substandard treatment. The open-tank method has been used in the past for many wood preservative treatments. In 1930, out of 4,276,031 poles treated in the United States, 1,817,227 received butt-treatment by the open-tank process.

Pressure treatments as a rule give deeper penetration of the preservative than any other type of treatment. Variations between the full-cell and empty-cell treatments allow the full attainable amount of penetration with varying quantities of the preservative. Many modern wood preservative materials are now applied by the pressure process.

Pressure treatments are of two general types, namely, the *full-cell*, or *Bethell Process*, and the *empty-cell*, or the *Rueping* and the *Lowry* processes. Pressure treatments, as used, are applicable only to the full-length treatment of poles and timbers. The preservative is applied by pressure-treating processes in large steel cylinders or retorts. The wood is placed in the treating cylinder, which is then filled with the preservative, and a pressure of 100 to 175 pounds per square inch (7 to 12 kg./sq. cm.) is applied to force the preservative into the wood. In the full-cell treatment a vacuum is applied to the retort to remove as much air as possible from the cells of the wood structure before the preservative is run into the retort. This allows the preservative to flow readily into the cells of the wood, where it remains at the conclusion of the treatment. With the Lowry empty-cell process the cells of the wood are allowed to remain full of air at atmospheric pressure when the preservative is run into the retort. In the Rueping empty-cell treatment the cells of the wood are filled with air under pressure (from 30 to 110 pounds per square inch, or 2 to 8 kg./sq. cm., is used, depending on the type of treatment desired) before the preservative is applied. The preservative is then forced into the wood under pressure until the desired absorption is obtained. In both empty-cell processes the final step is the application of a drying vacuum. The air in the cells forces the excess preservative out, leaving the cells empty and the wood relatively dry at the conclusion of the treatment.

Service records on thousands of full-length pressure-treated creosoted poles (principally southern pines) show less than 10 per cent renewals in 25 to 30 years of service. No replacements are necessary in lines 10 to 20 years old. The old poles, still in service, appear to be in excellent condition after 20 years or more of use. Empty-cell Rueping treatments do not give the years of service of the full-cell treatments. The cost of empty-cell treatment is less due to the smaller retention of preservative. The only records we have of empty-cell creosote treatments have come from a group of tests by the Santa Fe Railway Company at Cleveland, Texas. An empty-cell Rueping treatment with a retention of 2.68 pounds of creosote per cubic foot (42.9 kg./cu. m.) of wood showed considerable failure in 8 years of service. A retention of 5 pounds of creosote per cubic foot (80 kg./cu. m.) left the posts in excellent condition after 7 years of service. Both of these treatments were on Rocky Mountain type Douglas fir (New Mexico red spruce), which has a thin sapwood and consequently did not show much penetration of the preservative. Termites were found in the damaged poles of each of these tests. Southern yellow pine with a 5 pound per cubic foot (80 kg./cu. m.) empty-cell creosote treatment showed a softening of the posts, the first signs of failure, after 15 years. The full-cell treatment, with a retention, in this case, of 34.8 pounds of creosote per cubic foot (557.5 kg./cu. m.) had survived 18 years of service in perfect condition. No termites were found in the treated southern pine posts, which accepted a deeper penetration of the preservative because of the relatively greater amount of sapwood.

Tests were made by the U. S. Department of Agriculture at Falls Church, Virginia, from 1912 to 1922 for the purpose of investigating the protection from termite attack afforded by various methods of treatment. The results of these tests are aptly summarized by Dr. T. E. Snyder as follows:

> Impregnation by the open-tank method with coal-tar creosote renders wood resistant to attack by termites for at least fifteen years. Impregnation by the full-cell process with coal-tar creosote renders wood resistant for at least twenty-five years. . . . Brushing several coats of coal-tar creosote on timber will add from two to five years to its life. . . . The length of service required must determine whether the method is to be a superficial treatment or a more costly but permanent impregnation.

Importance of the treated shell.—The service of a wood-preserving treatment is greatly dependent upon the integrity of the shell of protected wood. Any break or puncture in the shell of preserved wood exposes untreated wood, which is susceptible to the attack of fungi and insects. Termite attack on wood exposed by a break in the treatment may be inhibited for some time if the preservative gives off toxic vapors or is otherwise noxious to the insects. A fresh creosote treatment is a good example of this. This protection is short-lived, however, and both fungi and termites attack the exposed, untreated wood at the first opportunity. All wood preservative treatments are subject to failure through damage to the shell of protected wood.

To obtain satisfactory service from treated wood the material must be both properly treated and properly handled. The treatment must form an unbroken outer layer of preserved wood which is thick and durable. Care must be taken that the protected shell is not damaged in the handling, inspection, or use of the material.

As shown in the above mentioned tests, the penetration of the preservative, or the thickness of the protected shell, is an important factor in the service-life of treated wood. The species of wood ordinarily used for poles, piling, etc., have a sapwood which readily accepts preservative treatment. Thus it is possible to obtain a treated outer shell the full thickness of the sapwood. Often lumber and timbers are composed entirely of heartwood, which is much more difficult to treat than sapwood. Even when subjected to pressure-treating processes, some few timbers accept little more than a surface treatment with the preservative. Commercial treatments of timber and lumber are usually judged by the amount of the preservative retained. The penetration of the treatment depends on the nature of the wood structure and varies considerably even in the standard treatment.

Seasoning.—The seasoning of wood before treatment is an important factor in the ease of applying the preservative and in the permanence of the treated product. Green or unseasoned wood cannot be treated satisfactorily by the above mentioned processes. The cells of the green wood are already filled with the sap and do not allow the penetration of the preservative. Seasoning is usually accomplished by keeping the green wood in drying yards six to twelve months before treatment. With modern treating methods and equipment wood can be artificially seasoned in the retorts just before the treatment is applied. This is accomplished by a steaming and vacuum treatment, or by boiling under vacuum in oil to remove the moisture from the wood. Seasoned wood allows the preservative to penetrate into the cells of the wood structure, thus giving a thicker and more uniform treated shell.

The seasoning of wood before treatment is also necessary to retain the integrity of the protective shell. All wood splits and cracks as the moisture dries out of it, the so-called weather checking. Weather checking continues throughout the life of the wood, particularly if it is exposed to the elements, but the greatest amount occurs during the earlier seasoning period. One of the common causes of failure of treated wood is in the checking which breaks the treated surface. Where frequent failure of this type occurs in treated material, the cause can usually be traced to improper seasoning before treatment. Failures of properly treated wood due to checking occur but rarely when the wood has been properly seasoned before treatment.

Framing of timber.—All wood, poles, timbers, etc., should be sized, framed, and bored before treatment. All cutting of the material to suit it to a specific use should be done before the preservative is applied, so the material will have a fully protected surface when and as it is used in the field. Often further shaping of the treated wood in the field is unavoidable. In such cases the freshly cut surfaces should be treated with several generous brush coats of a good preservative. This treatment is not so effective as the original impregnation, but it greatly lessens the chance of damage where the treated shell has been penetrated by cutting.

Most treated wood is framed (if framing is required) before treatment. Damage to treated wood occurs usually on jobs where only small quantities of treated lumber are used, as in the foundations of small structures; where plans of construction have been modified; or in the re-use of treated wood which has been salvaged. It is important to the life of treated wood that all freshly exposed surfaces be given a thorough brush treatment with a good preservative.

Inspections.—Treated wood is sometimes damaged by lack of proper care in inspecting it. Inspections to see that there has been proper penetration of the preservatives are made both by the treating company and by the purchaser of the material. Further inspections are made in the field throughout the useful life of the wood to ascertain its condition. A few specimens from every retort load of material are inspected by the treating company for penetration of the preservative. The inspection is made by boring into the wood with an auger so the penetration can be observed, or by boring with an increment borer which extracts a core through the treated shell. The damage done by this inspection is always cared for by driving a wooden dowel which has been thoroughly impregnated with the preservative into the hole. The dowel is always made somewhat larger than the hole so that a tight seal may be obtained.

The damage from field inspections is seldom properly cared for. The most striking illustration of this is the inspection of butt-treated poles to see that they are sound below ground line. The inspection is usually made by jabbing the pole at or below ground line with a sharp pointed steel bar, which breaks the protective shell of treated wood, with usually no effort being made to repair the damage to the treatment. Where such methods result in exposing untreated wood, fungi and termites can attack the pole. This method of inspection has no doubt started the failure of many serviceable butt-treated poles. A change in the method of inspecting butt-treated poles is recommended. A better inspection can be obtained by boring into the pole, at or below the ground line, and then repairing the damage as indicated above.

PRESERVATIVE MATERIALS

PROPRIETARY PRESERVATIVES

Only those preservative treatments which have been brought directly to the attention of the Committee, the treatments most often discussed on the Pacific Coast, and those which are commercially available in the United States, will be discussed here in some detail. Many preservatives which have attracted attention have been purposely neglected because of the secret nature of the materials. No fundamental knowledge could have been obtained from tests of materials of unknown chemical composition unless they had an established record as wood preservatives. As far as possible we have attempted to work only with those preservatives whose chemical composition was known to us. Wherever possible we shall include this information, so that the toxicities of the preservatives can be checked by comparing them with the toxicities of the pure chemicals involved in their composition.

Unless otherwise indicated, the information on the following preservatives was largely obtained from the manufacturers.

Anaconda treatments.—The Anaconda Copper Mining Company recovers large quantities of arsenic oxides from its smelting operation. The wood preserving treatments proposed by the Anaconda Company all involve the use of white arsenic, *i. e.*, commercial arsenious oxide, or arsenic trioxide. Arsenic oxides are among the cheapest toxic materials known. Arsenical compounds are very powerful poisons and are used extensively in insecticides. Extreme care should be taken to guard against endangering the public health when using poisonous arsenic compounds.

The Anaconda Copper Mining Company proposes two arsenical treating solutions known as *Anaconda Solution Regular* and *Anaconda Solution Neutral,* which are to be applied by standard wood preserving processes. They also have on the market an arsenic preservative, *Anaconda Wood Preservative,* to be applied to poles or posts at the time of setting, or to those already in place.

The *Anaconda Regular* and *Anaconda Neutral* treating solutions are solutions of arsenious oxide (white arsenic). The solutions are made with the aid of caustic soda, but the amounts of each chemical required by the specifications do not correspond to the formation of a definite chemical compound between them. The treating solutions are evidently water solutions of arsenious oxide, stabilized by caustic soda. These solutions are best discussed in the specifications for their manufacture.

The *Anaconda Solution Regular* contains approximately 5 per cent by weight of arsenic trioxide and 0.8 per cent caustic soda.

The *Anaconda Solution Neutral* differs from the *Anaconda Solution Regular* in that the alkalinity is reduced from 0.8 per cent caustic soda to approximately 0.05 per cent by the addition of a sufficient amount of 93 per cent sulfuric acid. This reduction in alkalinity accomplishes a two-fold purpose. First, since alkali is known to damage wood fiber, the chance of damage to the wood structure is decreased. The damage to the wood structure with the more alkaline *Anaconda Solution Regular* is, however, practically negligible. Second, the reduction in alkalinity decreases the water solubility of the treating mixture. This makes the *Anaconda Solution Neutral* somewhat less liable to leaching, more suitable for exterior use, and more permanent.)The usual retention of preservative solution gives about ½ pound of arsenic trioxide per cubic foot (8 kg./cu. m.) of wood. These treatments have been used by the

Anaconda Company in their mining operations for the past ten years and are stated to give complete satisfaction.

Extensive use of arsenic trioxide for wood preservation has not yet been made in the United States, probably because of the extremely poisonous nature of the preservative. Satisfactory preservation of wood from the attack of rot and termites has been obtained in India with arsenic trioxide. A 1½ per cent water solution of arsenic trioxide is used by the pressure process, treating the wood with ⅛ to ¼ pound of arsenic trioxide per cubic foot (2 to 4 kg./cu. m.), depending on the severity of insect attack to which it is subjected. It has been found suitable for exterior use.

Aside from the health hazard involved in its use, arsenic trioxide should be a cheap and good wood preservative. High toxic powers and a relatively low solubility in water, which should give it permanence, theoretically make arsenic trioxide an excellent wood preservative, but its value should be further proved by use in the field.

Anaconda Wood Preservative is a product of the Anaconda Copper Mining Company for the preservation of wood, *i. e.*, poles, posts, etc., coming in contact with the soil. The preservative is made from Cottrell Treater Dust, a by-product of the copper smelting operations. The material is now sold in two forms, granules and paste. The main toxic constituent is arsenic trioxide, which constitutes 70 to 75 per cent of the material.

The *granular form* has been recommended for round poles at the time of setting. The amount of preservative recommended is 10 to 15 pounds (4 to 7 kg.) per pole, depending upon the size of the pole. One to 2 pounds (0.5 to 1 kg.) of granules are put in the bottom of the hole as a uniform layer below the butt; 3 to 6 pounds (1.4 to 2.7 kg.) of granules are placed as a second layer around and against the pole at a point half way between the pole butt and a foot below ground line; a third layer of 6 or 7 pounds (2.7 to 3.2 kg.) is placed against the pole so the top of the layer will be about 10 inches (25 cm.) below ground line. The pole is then backfilled in the usual manner.

The procedure in connection with granular and paste forms of *Anaconda Wood Preservative* is to leave a generous amount of the slightly soluble material so that there will be a reservoir of toxic material in contact with the wood of the pole for many years. The slight amount of toxic material which dissolves in the soil moisture will sterilize the soil around the pole, and the toxic solution will be absorbed by the pole as by a wick. The treatment of the pole thus goes on during its life, impregnating the pole deeper and deeper with the preservative.

The absorption of the preservative by wick action is most noticeable in the weather checks. In extremely wet locations this wick action has been reported to carry visible amounts of the preservative to a height of 40 feet (12 m.) above ground. It is said to be an important factor in the success of this treatment, which was investigated later by this Committee.

Reports of failures of this treatment as used by the power companies in the arid regions of Arizona came to the attention of the Committee. These reports indicated the following conditions. The poles were of lodgepole pine treated at the time of setting with the older dust form of *Anaconda Wood Preservative.* The treatment was applied at the butt and in two rings of preservative, as specified. Extensive failure was occurring in these poles one to two years after treatment. Investigation showed damage by rot and the subterranean termite, *Heterotermes,* occurring between the rings of preservative (fig. 63). The lodgepole pine pole in the illustration was in service less than one year. In this very dry region there was evidently not sufficient ground moisture to dissolve the dry preservative.

An extensive test installation of *Anaconda Wood Preservative, dust form,* was made by the Pacific Telephone and Telegraph Company near the region of San Francisco Bay, in central California. Here the preservative was applied to untreated red cedar poles already in place. The dirt was dug away from the poles to a depth of 2 feet (0.61 m.) and a ring of the treater dust about 1 inch (2.5 cm.) thick (requiring about 1½ pounds, or 0.7 kg., of dust) packed around and against it. A second ring of the treater dust was placed about 6 inches (15 cm.) below ground line, as the pole was backfilled. The rotted wood was shaved from each pole before treatment from 2 feet (60 cm.) below, to 6 inches (15 cm.) above ground line. One pole in every four was left untreated, but the rotted wood was shaved from it by the same routine procedure. One of several consecutive test groups, consisting of three treated and one untreated poles, was inspected each year; the rot was shaved from each pole and the circumference of the remaining sound wood of the pole measured.

After three years all the test poles were removed and a thorough search was made by the Committee for termites. A preliminary inspection for termites was made at the end of the second year of the test, but since the inspection of standing poles for subterranean termites may give uncertain results, this inspection is considered inconclusive. Unless the pole has been removed so that the whole butt can be thoroughly inspected, failure to find subterranean termites in a pole does not prove their absence. The preservative value of the dust treatment, in the treated or prepared portion of the pole butt, is shown in the average figures for the decrease in circumference in the sound wood of the pole.

One year after treatment:

- 13 untreated poles 0.231 inch (0.587 cm.) average decrease in circumference
- 46 treated poles 0.228 inch (0.579 cm.) " " " "

Two years after treatment:

- 16 untreated poles 1.000 inch (2.54 cm.) average decrease in circumference
- 44 treated poles 0.216 inch (0.549 cm.) " " " "

In most cases when these poles were removed no termites were found in the butts, although damage by the subterranean termite, *Reticulitermes hesperus,* and by the dry-wood termite, *Kalotermes minor,* was evident. The application of arsenical dust packed around the butt of the poles had evidently protected the poles to some extent from further damage. Live subterranean termites were found in practically all of the untreated poles. The poles which had been treated for three years showed the presence of subterranean termites only rarely. The capillary rise of the *Anaconda Preservative* in the pole was evidently small, since live dry-wood termites were found in the upper parts of many of the poles, even down to the ground line.

This arsenical treater dust has also been tested in the U. S. Bureau of Entomology test yard on Barro Colorado Island, Panama. There the conditions of termite attack are extremely severe, and the test stubs were attacked after one and a half years. The same material (Cottrell Treater Dust) was included in a world-wide test series, the International Termite Exposure Test, and showed good protection in one and two year exposure periods of the test groups.

The *paste form* of *Anaconda Wood Preservative* has about 70 per cent of arsenic oxides and 26 per cent of water, the remainder being small amounts of salts of copper, lead, and zinc. It is recommended for application to old poles in place and to new poles in areas of low rainfall. A hole is dug around the pole to a depth of 18 to 24 inches. All rotted wood is removed from this portion of the pole with a wide-faced chisel or "slick", and the paste applied with a curved spatula. It is plastered on the pole surface from the bottom of the excavation to the surface of the ground, maintaining an average thickness of ¼ inch. About 10 to 12 pounds of the preservative paste is required to treat a pole 10 inches in diameter. The dirt is backfilled and tamped around the pole in the usual manner. The fill should leave none of the arsenic paste exposed, because of its very poisonous nature.

Six poles, western red cedar and square redwood, infested with the subterranean termite, *Reticulitermes hesperus*, were treated, with the cooperation of the Committee, with *Anaconda Wood Preservative Paste*. The rotted wood was not shaved from the poles, as recommended for the application of the paste. It was thought that the termites would probably leave the pole on being disturbed by the removal of the rotted wood, and as the test poles were scheduled to be removed in a short time, reinfestation might not occur before the close of the test. With this exception, the paste was applied according to the recommendation of the manufacturer, using about 10 pounds (4.5 kg.) per pole. The estimated average cost of treatment was $1.77 per pole. The poles were removed for inspection eight and a half months after treatment. During this period the total rainfall had been 5.89 inches (14.96 cm.).

Of the three red cedar poles treated, live subterranean termites were found in two at the time of treatment, and workings of the insects were found in the third. Live subterranean termites were found in none of the poles at the conclusion of the test. One of the poles, which was in very moist soil, had dead termites in it.

Live subterranean termites were found in the butts of the three square redwood poles at the time of treatment. Inspection showed live termites in two of these poles at the conclusion of the test. One of these poles, set in moist soil, was showing the effect of the treatment, as many dead termites were found. The third pole, also set in moist soil, was no longer infested.

These results cannot be considered conclusive, but they appear very encouraging. No doubt the effectiveness of the treatment would have been increased by the removal of the rotten wood, as recommended. Where live termites were found in these poles they were usually under the surface layer of decayed wood, which seemed to protect them from the arsenic poison.

Another test installation of *Anaconda Wood Preservative Paste* was made with the cooperation of the Committee, on fir and cedar poles in the vicinity of Los Angeles. The poles were located along a highway and were readily accessible. This made the cost of treatment low—$1.53 per pole.

One of the public utility companies of Arizona treated, in 1929 and 1930, about 500 old poles in place with *Anaconda Wood Preservative Paste*, at an average cost of $2.50 to $3.00 each. The oldest of these treatments has been in service little more than two years, but it is evident from inspections made with the cooperation of the Committee that damage by both rot and termites has been greatly arrested. Damage by these agencies has gone on very rapidly in untreated poles, while the condition of the treated ones has changed but little since the treatment. It is still too early to judge from these installations the ultimate value of this paste treatment, but present results seem promising.

From chemical analyses of increment borings taken from two test pole stubs it is evident that there is a capillary rise of the arsenical preservative, and that this occurs almost entirely in the sapwood of the pole. This capillary distribution of the preservative may be of importance in pole preservation in very damp climates, but it is extremely slow in the drier climates of central and southern California and Arizona. Further analyses to test the rise of the preservative in the poles should be made during the period of service of this treatment.

A study was also made of the radial penetration of arsenic in poles treated with *Anaconda Wood Preservative Paste,* in the vicinity of Yuma, Arizona. Increment borings, taking out a core approximately ¼ inch (0.6 cm.) in diameter, were made at the ground line of fifteen cedar poles which had been treated, in cooperation with a member of the Committee, twelve to eighteen months previously. These samples were analyzed at the laboratory of the Anaconda Copper Mining Company. The average of the analyses on these fifteen poles showed that the outer or surface inch contained 0.291 per cent of arsenic trioxide; and the second inch contained 0.007 per cent. There was evidently a slight radial penetration of the preservative in the twelve to eighteen months of service.

Anaconda Wood Preservative is, to our knowledge, the only preservative recommended by the manufacturer for old poles in place. Neither the granular nor the now discontinued dust form of this preservative is suitable for use in arid climates or regions of low rainfall. The manufacturer now recommends the paste form for such locations. No field observations or service records of the paste in arid locations are yet available for judging the value of the treatment under such conditions.

Where there is at least a moderate rainfall, *Anaconda Wood Preservative* shows some promise of preventing damage to poles by the subterranean termites. The recommended treatment will cost from $1.50 to $3.00 per pole, depending on the accessibility of the poles. Treated poles removed for observation have shown a reduction in damage done by both subterranean termites and fungi during the few years which they have been in use. Poles treated with *Anaconda Wood Preservative Paste,* inspected in place, have shown much less damage by rot and termites in the treated portion than in untreated poles. However, since the capillary rise of the preservative is very slow in regions of moderate rainfall, this feature cannot be expected to protect the body of the pole from the attack of dry-wood termites. The absorption of the dissolved poison by the butt of the pole affords protection from the subterranean termite.

Finally, we wish to repeat that the toxic element of *Anaconda Wood Preservative* is a strong poison. This preservative should be handled with care, and should be so used that none of it is left exposed as a possible danger to those who may come in contact with it.

Ac–Zol.—The preservative *Ac–Zol* was invented by a Belgian chemist and is distributed in Europe by the Compagnie Generale de l'Ac–Zol. It is manufactured and sold in the United States by Zinsser and Company, Inc., Hastings-on-Hudson, New York. The treating fluid consists of salts of copper, zinc, and phenol held in solution in water by the presence of ammonia. In seasoning after treatment the ammonia evaporates, allowing the copper and zinc phenolates, which are not appreciably soluble in water, to precipitate in the wood. The claim of permanence against leaching and weathering is based on the low solubility of these resulting phenolates.

The constituents of *Ac–Zol* are so proportioned that they are all used in chemical combination to form the insoluble copper and zinc phenolates. Because of this it is said that the *Ac–Zol* treatment can be applied in the standard iron pressure-treating equipment without damage to the iron. Brass is damaged by the treating solution and all brass should be replaced by iron. The treated wood, when seasoned, is clean and without odor, but has a dark color. *Ac–Zol* treated material can be used and handled without danger of poisoning from the treatment.

Wood treated with *Ac–Zol* by a pressure impregnation process was exposed to termite attack in the Barro Colorado Island test yard of the U. S. Department of Agriculture. For the latest report on this test see Table 37.

Reports of fourteen years of experiment on wood preservatives by the Forest Research Institute of the Government of India give results on preservatives applied by soaking the test specimens for about one hour. *Ac–Zol* applied in this manner has shown little permanent protective value, but during the first few years of the test there was almost no damage by rot or termites.

On these meager service records it is impossible to judge the value of *Ac–Zol* in comparison with other better known preservatives.

Bruce Preservatives, formerly known as the *T–R–I Treatment,* were developed in the laboratories of the Bruce Chemical Corporation in 1926. There are now three types of *Bruce Preservative,* each adapted to a specific purpose. These preservatives, known as *5A, 5B,* and *5C,* all contain the same toxic ingredient, a known organic chemical, of slight solubility in water, and known to be toxic both to fungi and termites. This chemical has been investigated by the Committee, but its name cannot be disclosed in connection with *Bruce Preservatives* until pending negotiations for patent protection have been settled.

According to the E. L. Bruce Company of Memphis, Tennessee, who are promoting the *Bruce Preservatives,* these treatments were devised particularly for the treatment of lumber and wood used in fabricated products. These preservatives are not proposed for the treatment of posts, poles, and large structural timbers (for bridges, etc.) where the wood is in contact with the soil and subject to severe weathering conditions.

Bruce Preservatives are all applied by the open-tank method. No specification regarding the time of treatment is made, as it depends on the species, size, and texture of the lumber, and the desired penetration and retention of the preservative. Lumber should be dried and seasoned before treatment, as there is better penetration and less damage in the treatment of dry material. This method of treatment requires comparatively inexpensive equipment. The largest part of the cost of *Bruce Preservatives* is said to lie in the preservatives themselves and not in the treating process, making their total cost comparable to that of other preservative processes.

Other advantages, also, are claimed for *Bruce Preservatives.* They are practically odorless; the use of a non-poisonous preservative material allows handling of the treated product as if it were untreated timber; the chemical preservative is applied to the lumber in solution in oil, or in light, volatile petroleum solvents; the treating process is so arranged that the moisture content of the already seasoned wood is changed as little as possible. This eliminates the after-treatment seasoning period necessary for water-soluble preservatives. Since this seasoning after treatment is eliminated, there is no distortion of checking after processing. The wood may therefore be fabricated before treatment.

Bruce Preservative 5A is intended for lumber used out-of-doors, in full exposure to the weather, unprotected by paint, and which must resist leaching. The preservative is applied dissolved in heavy petroleum oil. Due to the presence of the oil, it does not leach out of the wood so easily as treatments *5B* and *5C*. The lumber is soaked in a bath of *Preservative 5A* at about 180°F., where it absorbs the treating solution. It is then plunged into a bath of the cold preservative and allowed to cool. Due to the contraction of the air in the wood cells on cooling, more preservative is absorbed, and a part of the toxic chemical which saturated the hot preservative is precipitated in the wood. The recommended treatment is 4.4 pounds of oil per cubic foot (70 kg./cu. m.). "*5A* preserved lumber has an oily appearance; is black in color; has no objectionable odor; does not readily accept paint; and should not be used in contact with materials where the staining it may produce would prove objectionable."

Bruce Preservative 5B has the same toxic material, but is applied in solution in a light volatile petroleum solvent. The lumber is preheated in a kiln, without changing its moisture content, and is then plunged into a bath of the cold preservative, where it remains until proper penetration of the preservative is obtained. After treatment the volatile solvent soon disappears, leaving the dry preservative. The recommended retention of dry preservative is 0.35 pounds per cubic foot (5.6 kg./cu. m.). The treatment is colorless and odorless, and it is said that paint can be successfully applied over it, or the lumber can be stained, shellacked, varnished, puttied, or waxed as desired. This treatment is designed for structural or interior woodwork in houses, or other sheltered construction, but can be used out-of-doors when protected by paints.

Bruce Preservative 5C.—In some cases a distinctive color may be desired for the purpose of recognizing the preserved stock after long periods of use. *Preservative 5C* meets this need. It is identical with *5B* and is applied in the same way, but imparts a black color to the treated wood.

Use of Bruce Preservatives.—The E. L. Bruce Company reports a growing use of their preservatives in southern and eastern United States. There has as yet been no extended use of them on the Pacific Coast, and the Committee has no field observations on these treatments.

Tests of *Bruce Preservative 5A* have been made in the termite test yard of the U. S. Bureau of Entomology on Barro Colorado Island, Panama. Under the severe conditions there current *Bruce Preservative 5A,* set in the soil, was attacked by termites in ten months. Indications from our laboratory tests show that these preservatives would probably give much more lasting protection above ground.

Reilly Transparent Penetrating Creosote.—A proprietary coal-tar product developed in the Reilly Laboratories of the Republic Creosoting Company, Indianapolis, Indiana. The preservative is manufactured and sold by this company. They state that the preservative is a highly refined, blended coal-tar creosote oil from which have been removed those substances which impart color and odor to the oil, and also those which impede penetration into the wood. The oil was developed to fill a need for coal-tar creosote free from the objectionable qualities of crude creosote oil, such as (1) its color; (2) its odor, particularly in homes, because of the susceptibility of certain foodstuffs, including butter and eggs, to its odor; and (3) the difficulty of color-painting wood treated with it. The *Reilly Transparent Penetrating Creosote* overcomes these objections and is considered a distinct advance in the art of wood preservation.

It was not received in time to be tested by the Subcommittee on Chemistry. A report on the tests made by the Subcommittee on Biology appears in Table 45. These tests show that wood impregnated with a 12 per cent solution in a volatile solvent remains toxic to termites after 43 days of drying over a steam heated radiator. The average rate of kill for 80 per cent of all termites in the tests on pressure-treated wood was 15 days for a 25 per cent solution and 17 days for a 12 per cent solution.

Solwax.—A proprietary preservative developed in the Reilly Laboratories of the Republic Creosoting Company, Indianapolis, Indiana, and manufactured and sold by them. The company states that *Solwax* is a non-aqueous, rapidly penetrating material compounded from coal-tar derivatives in such a way that its odorless toxic ingredients are permanently fixed in the wood.

Solwax was not received in time to be tested by the Subcommittee on Chemistry. A report on tests made by the Subcommittee on Biology appears in Table 45. These tests show that wood impregnated with the preservative is toxic to termites and that a high rate of kill is effected by it.

Halowax.—This is a wax-like preservative manufactured by the Halowax Corporation, New York City. *Halowax* is chlorinated naphthalene, and the grade used to protect wood products from insect attack approximates a trichloronaphthalene. The *Halowax* treatment is usually applied by soaking the wood in the molten wax at about 105°C. The time of soaking depends on the amount of wax desired in the wood. There has been no standard specification for the amount of *Halowax* necessary to prevent insect attack. *Halowax* has a slight but characteristic odor, and is practically non-water-soluble. The grades of *Halowax* used for wood treatment cost from 20 to 36 cents a pound. This makes it impractical for general use in wood preservation, but it is recommended by the manufacturer for the treatment of finished and interior woodwork and furniture. Wood treated with *Halowax* has been found paintable, and can be stained, shellacked, or varnished.

The first recorded tests of *Halowax* for preventing termite attack were started by the U. S. Bureau of Entomology at Falls Church, Virginia, about 1913. The blocks were buried in soil infested with the subterranean termite (*Reticulitermes* sp.). The results of three years' exposure showed the *Halowax* treatment had not made the wood completely immune to termite damage, but the woods which were very susceptible to attack had been made highly resistant.

The U. S. Bureau of Entomology at Barro Colorado Island, Panama, also exposed wood treated with *Halowax* to attacks of the subterranean termites. As a result of these tests it was concluded that *Halowax* was a suitable treatment for timber not to be used in contact with the ground. For the latest report on these tests see Table 36.

Test specimens for the International Termite Exposure Test were treated by pressure impregnation with molten *Halowax*. All samples were set in the ground for exposure. Samples in Panama, which had on the average absorbed 19.10 pounds of *Halowax* per cubic foot (306 kg./cu. m.) of wood, have survived twenty-five months with no attack. In South Africa samples containing an average of 21.10 pounds of *Halowax* per cubic foot (338 kg./cu. m.) were not attacked in twenty-three months of exposure. Similar samples in Australia and Hawaii had not been damaged at the end of one year's exposure.

Another test of *Halowax* treated material was conducted in Hawaii. The samples were prepared by soaking in the molten wax at 105°C. The results reported after six months' exposure to termites show little attack.

Lignophol.—This is a preservative material manufactured and distributed by L. Sonneborn Sons, Inc., New York City. It is made in two forms, *Lignophol Natural* and *Lignophol Fungicide*. The manufacturers state that *Lignophol* is made by blending the oils, hard gums, and penetrating solvents obtained from the distillation of wood. *Lignophol Fungicide* contains an additional amount of phenolic compounds to enhance its antiseptic properties. The material costs about $3.00 a gallon. It is reported as a preventive for fungus damage, but is considered non-poisonous.

Lignophol has great penetrative power, and the recommended method of application is a 15-second immersion of the wood in the substance, or a generous brush treatment. In the more easily treated woods, such as oak and pine, a penetration of about ½ inch (1.25 cm) can be obtained. Wood treated with *Lignophol* appears oily at first, but the treatment dries in a few weeks and can be painted or varnished over satisfactorily. *Lignophol* is proposed by the manufacturers only for the treatment of new or uninfested material.

Wolman Salts.—A preservative mixture for the treatment of wood was patented in Germany by Dr. Karl Heinrich Wolman, and was brought into use there about 1907. The preservative basis of this material was sodium fluoride and dinitrophenol. Since that time four preservatives have come on the market under the name *Wolman Salts, i. e., Triolith, Minolith, Tanalith,* and *Tanalith–U*. All of these salt mixtures have the same basic preservative material, but the compounding of each has been arranged to meet some special demand of the wood preserving industry. These preservatives were used extensively by mines and railroads in Germany during the war. *Wolman Salts* are now available in the United States through the American Lumber and Treating Corporation, Chicago, Illinois.

Triolith is the trade name of the fundamental salt preservative of the Wolman group. It consists principally of sodium fluoride and dinitrophenol in the ratio of 90 per cent to 10 per cent by weight, and has about 5 per cent of chromates added to it. The purpose of the chromates is to neutralize the acid reaction of the dinitrophenol, and to mordant or set the preservative in the wood to increase its permanence when exposed to weathering. The preservative salt is yellow in color and nonhydroscopic. *Triolith* is used for timber treatment as a 2 per cent solution in water. The treatment is applied by the full-cell pressure impregnation process with the solution at 70° to 80°C. The recommended amount of preservative is 0.2 to 0.3 pound of salt per cubic foot (3.2 to 4.8 kg./cu. m.) of wood. Due to the neutralizing reaction of the chromates it is said that *Triolith* can be applied by the standard iron pressure-treating equipment without damage to the metal parts.

Minolith is the *Wolman Salt* preservative designed to give the treated wood some degree of fire protection. The preservative part of this salt is identical with *Triolith,* but 4.2 per cent of salt (sodium chloride) is added to the treating solution for fire resistance.

Triolith and *Minolith* are both wood preservatives, but they are not recommended by the manufacturer for wood subjected to the attack of wood-destroying insects. *Tanalith* is the name of the salt preservative made for this specific purpose. As far as we have been able to learn, *Tanalith* is composed of approximately 50 per cent sodium fluoride, dinitrophenol, and neutralizing chromates as proportioned in *Wolman Salt Triolith,* and 50 per cent sodium arsenate. *Tanalith* is applied by the full-cell pressure impregnation process in the same manner as *Triolith,* outlined above.

Authentic extensive service records on material treated with *Wolman Salts* have not been found. *Wolman Salts* have been used most extensively in Europe. They have been in use in Germany for about twenty years on railroad and mine timber. *Tanalith* has recently been used to some extent for the treatment of mine timbers in the United States.

The Standard Fruit and Steamship Company has its own treating plants in Central America and is said to have in service over fifteen million board feet of lumber treated with *Wolman Salts*. This wood, treated with *Tanalith*, finds general use as poles, bridge structures, and lumber for dwellings and railway cars. Most reports on this material are superficial and of uncertain accuracy.

In a recent discussion of Wolman Salts we learned that tests of the Forest Research Laboratory in India had shown both *Triolith* and *Tanalith* unsuited to the severe conditions found there.

Results from the U. S. Bureau of Entomology test yard on Barro Colorado Island, Panama, showed that timber impregnated with *Triolith* and set in the soil was attacked by termites in two years, and so badly damaged that the test was closed at that time. There were also two groups of specimens treated with *Tanalith* and set in the soil; one was attacked by termites in two years, the other in six years and two months.

The treated specimens of the International Termite Exposure Test were set either in the ground or in active termite nest mounds. In Panama, exposure for twenty-five months showed 100 per cent of the *Triolith* specimens destroyed by termites, while 50 per cent of the *Tanalith*-treated material was destroyed, and the other 50 per cent attacked. Twenty-three months' exposure in South Africa showed 100 per cent of the *Triolith* specimens, and 50 per cent of the *Tanalith* specimens attacked by termites. One year's exposure in Hawaii showed only 14 per cent of the *Triolith* attacked. From an analysis of the data of these tests it is evident that *Tanalith* treated material is at first resistant to termite damage, but the preservative has not sufficient permanence, when used in the ground, to give continued protection.

Tanalith-U is the newest of the *Wolman Salt* preservatives. This new preservative is supposedly much the same as the old *Tanalith*, but proportions of the ingredients have been slightly readjusted to increase the permanence of the preservative for outdoor use. It is claimed that after full-cell treatment with an aqueous solution of the impregnating salt, difficultly soluble salts are precipitated in the wood fiber during the time of drying. These, it is said, cannot be leached out of the wood even under severe conditions, and will preserve the wood during its service life. The treating process for *Tanalith-U* is the same as that used for the application of *Tanalith*. We know of no results of field tests or service records on the use of *Tanalith-U*. This preservative is new and sufficient time has not elapsed to obtain results of field experiments.

Zinc-Meta-Arsenite.—This preservative, commonly known as *ZMA*, is now handled by the Curtin-Howe Corporation, New York City. It was developed several years ago in the laboratories of the Western Union Telegraph Company. *Zinc-Meta-Arsenite* has been on the market only a few years. The first field tests of this treatment were installed in the test yard of the Western Union Telegraph Company at Mattawan, New Jersey, in 1927. The process has been commercially available for only about three years, and consequently the Termite Investigations Committee believes the true value of the treatment is yet to be proved. *Zinc-Meta-Arsenite* treated material has been under test in the U. S. Department of Agriculture test yard on Barro Colorado Island. For the latest report on these tests see Table 36.

Material treated with *Zinc-Meta-Arsenite* is not discolored by the treatment; the wood is somewhat whiter than natural, due to the inclusion of the white precipitate of *ZMA* in the fibers. The treated wood can be painted satisfactory. The owners of the process also state that the wood can be handled and worked without danger to the workmen.

Other fluoride-organic preservatives.—These are a large group of salt type wood preservatives made by variously compounding sodium fluoride and organic nitro compounds, of which the above discussed *Wolman Salts* are typical.

Dinitrophenol has been used as a wood antiseptic since 1885. In that year a compound named *Antinonnin* appeared. The first known patent on this type of compound for wood preservation was issued in France in 1887, but no commercial use was made of it at that time. Basilius Malenkovic, an Austrian engineer, began a series of experiments in 1900, using sodium fluoride as a timber preservative. By 1903 he had prepared combinations of sodium fluoride with dinitrophenol analine and sodium dinitrophenolates. Within a few years there appeared on the market many commercial preservatives such as *Basilit, Fluoxyt, Hylinit, Wolman Salts,* and others. All of these used the same fundamental materials as did Malenkovic, combined with small amounts of other materials, or with a slight change in the organic constituent.

Antinonnin was the first of these preservatives, made in 1885. It is composed essentially of orthodinitro potassium cresolate. A recent experiment with this material by a railroad company in Texas showed fence posts treated with it lasted only seven to ten years, as against six years for untreated posts.

Basilit, or *Basilite* (also known from 1909 to 1911 as Bellit), is the commercial preservative which resulted from the experiments of Basilius Malenkovic from 1900 to 1909. Its composition is 88.89 per cent sodium fluoride and 11.11 per cent dinitrophenol aniline (*i.e.*, the acid of the dinitrophenol preservative has been neutralized with analine). *Basilit* is applied to the wood in a hot-water solution, either by open-tank or pressure impregnation methods. It seems to have had considerable use in Germany and Austria. Reports of these installations show that *Basilit* is in all probability a good and economical wood preservative. We have not been able to find any report of the use of the product in America, and there is no information on its value.

Malenit is another European preservative of the same type. It is composed of sodium fluoride and dinitro orthocresol. The acid of the dinitro orthocresol is neutralized in this case with soda and a double salt of antimony fluoride.

The preservative *Syllit* is used in Sweden. It is composed chiefly of sodium fluoride to which small quantities of other toxic agents have been added.

"STANDARD" PRESERVATIVES

The American Wood-Preservers' Association, the U. S. Department of Agriculture, and others constantly refer to coal-tar creosote and zinc chloride as "standard wood preservatives." We have heard much criticism of this practice by the manufacturers of other preservative materials.

The treating processes now in use for the application of coal-tar creosote and zinc chloride to wood were patented in 1838. Although many other treating processes were proposed about that time, the two "standard" treatments are the only ones which have survived the test of time. Service records for the past forty years are available for these two treatments, and their economic advantage has been thoroughly proved. Many promising preservatives have been produced in recent years, but they cannot as yet show records of service such as those now available for the so-called standard preservatives.

Creosote (coal-tar creosote).—Experiments were carried on both in England and America as early as 1756 on the use of vegetable tars and creosote-like materials for wood preservatives. The use of creosote as a wood preservative developed rather slowly. The value of the creosote process as compared to many of the other preservatives became apparant only after years of service. Even among the users of creosote there was much controversy over the grades and specifications of the coal-tar distillate suited for wood preservation. As creosote became cheaper and more uniform in quality, and as years of service proved the economic value of the preservative, the use of the creosote treatment became more general.

Creosote came into common use as a wood preservative in the United States with the erection of a pressure-treating plant for the application of creosote at Somerset, Massachusetts, in 1865. This plant was used by the Dighton & Somerset Railway until 1870 to treat piling for bridges. In 1876 a pressure-treating plant was built at West Pascagoula, Mississippi, to treat wood for the Louisville and Nashville Railway, and material known to have been treated there is still sound and in use after forty years of service. Another plant was built at about the same date in Slidell, Louisiana, by the New Orleans and Northeastern Railway. An idea of the growth of wood preservation and the extensive use of creosote as a preservative can be obtained from the fact that in 1904 there were only thirty-three pressure-treating plants in the United States using creosote, while in 1931 there were one hundred and forty.

Through the efforts of the American Wood-Preservers' Association and the American Railway Engineering Association, wood preservation in the United States with standard preservatives has been put on a well standardized basis. Specifications for the purchase and test of grades of coal-tar creosote suitable for wood preservation have been agreed upon. Specifications for the routine of the recommended treating procedures have also been published by the American Wood-Preservers' Association and others.

Years of service have proved creosote a satisfactory and economical wood preservative, although its color and odor, its tendency to stain, and the impracticability of painting over it make it objectionable for use on interior finish and woodwork. Where the mechanical life or the desired life of treated wood is less than that of creosoted material, a diluted creosote is often used. For example, many railroads treat their ties with a creosote and fuel oil mixture, in which 30 per cent to 55 per cent fuel oil is used. Here the fuel oil not only dilutes and cheapens the treating liquid, but adds bonding and mechanical life to the tie. The long life of full-cell creosote treated material is shown by the service records of poles. These show less than 10 per cent renewals in twenty-five to thirty years of service, with the old poles still appearing in splendid condition. Lines of creosoted poles often show no replacement in ten to twenty years of service. The actual service life to be expected of adequately pressure-treated creosote poles is still unknown.

Coal-tar creosote and subterranean termites.—The results of tests by the U. S. Bureau of Entomology at Falls Church, Virginia, 1909–1922, to determine the resistance of creosote-treated material to subterranean termite attack are reported by Dr. T. E. Snyder in *Tests of Methods of Protecting Wood against Termites or White Ants,* U. S. Department of Agriculture Bulletin No. 1231, June 26, 1924. More recent tests by the U. S. Bureau of Entomology on Barro Colorado Island, Panama, include two sample groups treated by impregnation with coal-tar creosote and exposed to subterranean termite damage. For the latest report on these tests see Table 37.

The coal-tar creosote group of the International Termite Exposure Test (p. 404) was treated by pressure impregnation, the wood retaining an average of about 13.2 pounds of creosote per cubic foot (211 kg./cu.m.). After exposure to subterranean termites for twenty-five months on Barro Colorado Island, Panama, twenty months in South Africa, and twelve months in Australia and Hawaii, they were all in good condition and free from termite attack.

Creosoted wood was included, also, in a group of test specimens exposed in 1905 to attack of decay and termites in the Philippine Islands. This test was installed by the Philippine Bureau of Forestry through the U. S. Forest Service. The test specimens were of woods available in western United States. They were artificially, or steam, seasoned, and impregnated with coal-tar creosote by the full-cell process. The specimens were untouched by fungus or termites in 1908 and were still undamaged in 1921, after sixteen years of exposure.

Open-tank butt-treated poles exposed to the subterranean termite begin to show an appreciable amount of damage only after about fifteen years. Full-length, pressure-treated poles have not been used extensively on the Pacific Coast in the past. The few full-length creosote pressure-treated poles we have had the opportunity to observe have shown no sign of failure in twelve to seventeen years of service.

The treated fence post test of the Santa Fe Railway at Cleveland, Texas, gives results of interest on creosote treatments. Southern pine posts treated with coal-tar creosote by the Rueping, or empty-cell, process retained an average of 5 pounds of creosote per cubic foot (80 kg./cu.m.). The posts showed some softening, the beginning of failure, after fifteen years of exposure, but had no termites in them. Full-cell treated posts which had been in the ground seventeen years showed no sign of failure. Posts of Rocky Mountain type Douglas fir, which has a thin sapwood, retained only 2.68 pounds of creosote per cubic foot (42.9 kg./cu.m.) when treated by the empty-cell process. These posts showed signs of decay after eight years and had a few termites in them. Similar posts treated by the full-cell process retained 5 pounds of creosote per cubic foot (80 kg./cu. m.) and were in good condition after eight years' exposure.

A number of failures of creosoted wood due to termite attack, which came to the attention of our cooperating and contributing companies, were reported to the Committee. Each of these failures reported in California was investigated by one of our field men; those reported from other places were traced by correspondence. The value of creosote for preventing damage by termites was further illustrated in the inspection of these reported failures. No failures were found which could be ascribed to insufficient toxicity of creosote. The wood which was actually penetrated by creosote was never found attacked by termites, although some of the material inspected had been in the ground from twenty-five to thirty-five years. Most of these failures were due to the mechanical factors of wood preservation, and not to the preservative.

Failures of creosote-treated poles have been traced to the practice of jabbing a pole with a crowbar to test its soundness below ground. Where the injury to the pole had penetrated beyond the treated shell, exposing untreated wood, the pole was attacked by rot and termites. Sometimes the injury to the protective shell of treated wood had evidently occurred from the use of bars and cant hooks in setting the pole. A common cause of failure in creosote treated timber was the cutting or framing of the wood after treatment, thus exposing unpreserved wood directly to attack. Other failures were due to poor penetration of the preservative, or were caused by excessive weather checking which exposed untreated wood. The most striking of these failures were believed to result from improper seasoning of the wood before treatment. Some poles which showed good penetration and must have been properly treated also failed through deep weather checking or because the poles accepted the treatment unevenly, leaving a weak spot in the treated shell. These cases were extremely rare. The Termite Investigations Committee believes that wood treated with coal-tar creosote under pressure and in accordance with the standard specifications of the American Wood-Preservers' Association will give satisfactory protection under all known conditions. Such treated wood fulfills the requirements for wood adequately resistant to termites as defined in this report (p. 540) under an extremely wide range of use, climatic conditions, and exposure to termites.

Creosote and dry-wood termites.—Data on the effectiveness of coal-tar creosote for preventing the attack of the dry-wood termite are not nearly so extensive as those for subterranean termites.

A few full-length creosote-treated poles were put in service in 1913 and 1915 by the San Diego Consolidated Gas and Electric Company. They had been treated by a full-cell impregnation process. These poles were set in a district where untreated poles are now badly damaged by the dry-wood termite, *Kalotermes minor*. In fifteen to seventeen years of service these creosoted poles have shown no damage from termites.

The Southern California Edison Company has adopted a standard for treating their poles which involves an open-tank butt-treatment followed by a full-length open-tank treatment in grade A creosote. After natural seasoning the poles are given a butt-treatment to a height of 7 feet (2.13 m.), being allowed to stand in the creosote bath for 20 hours. The creosote is kept at 200° F. (93° C.), for 1 to 3 hours and allowed to cool for the remaining time. This open-tank treatment usually gives full penetration of the sapwood of the pole by the creosote. The poles are then removed to a tank where they are completely covered with creosote held at 180° to 200° F. (82° to 93° C.) for 1 hour, and then allowed to cool for 5 hours before removal. This gives about ¼-inch (0.6-cm.) penetration of the creosote in new western red cedar poles. This full-length treatment has been in use for only about 4 or 4½ years. When set in the field, these poles have often been observed to check through to untreated wood. They have been carefully watched and, although they are placed in districts infested with the dry-wood termite, *Kalotermes minor*, no attack has yet been found in them. This treatment does not give the same depth of penetration as a pressure-impregnation creosote treatment; however, it is much cheaper and has proved satisfactory to date.

Old poles which have been infested with dry-wood termites are also given this treatment. The pole may be extensively attacked, but if its strength is not seriously impaired it is salvaged. The badly infested ends are cut off, and the sapwood, which is usually riddled with the galleries of the insects, is shaved off. The pole is then given both butt- and full-length open-tank treatments with creosote, as described above. These old poles, from which the sapwood has been removed, do not absorb so much creosote as new poles. About $3.00 worth of creosote is required for one of these poles. The full-length treatment kills all the termites in the pole. The old poles which have already been in service ten to fifteen years do not check so much as do the new ones; in fact, checking sufficient to expose untreated wood rarely occurs, although the penetration of the creosote is less than in new poles.

It is essential, of course, that the termites in the salvaged pole be killed, and practical tests showed that this could be accomplished by the full-length creosote treatment. The creosote did not travel far through the extensive insect galleries, but from the way in which the termites had crowded to the far ends of their galleries, it was believed their death was caused by fumes from the creosote. The question of the effects of heat and creosote fumes in killing termites was studied in the laboratory of the Southern California Edison Company. The first experiment showed the dry-wood termite, *Kalotermes minor*, was killed by heat at 51.5° to 52.0° C. These results have since been confirmed in the laboratories of the Committee. The fumes of creosote at 20° C. killed the dry-wood termite in from three to four hours. By raising the temperature and increasing the concentration of the creosote fumes the insects were killed in a few minutes. The results of experiments on death rates among termites placed 6 inches (15 cm.) above creosote held at a constant temperature are shown in figure 116.

The temperatures in the poles during treatment were studied by placing maximum thermometers in holes bored in the poles at top, butts, and sides. The thermometers were sealed in and the poles subjected to the regular full-length treatment. The thermometers placed in the sides of the poles, near the center, did not rise above 34° C. during the treatment. At the ends of the poles temperatures of 54° to 62° C. were recordered. It will thus be seen that the temperatures attained throughout the length of the pole were not sufficient to kill the termites.

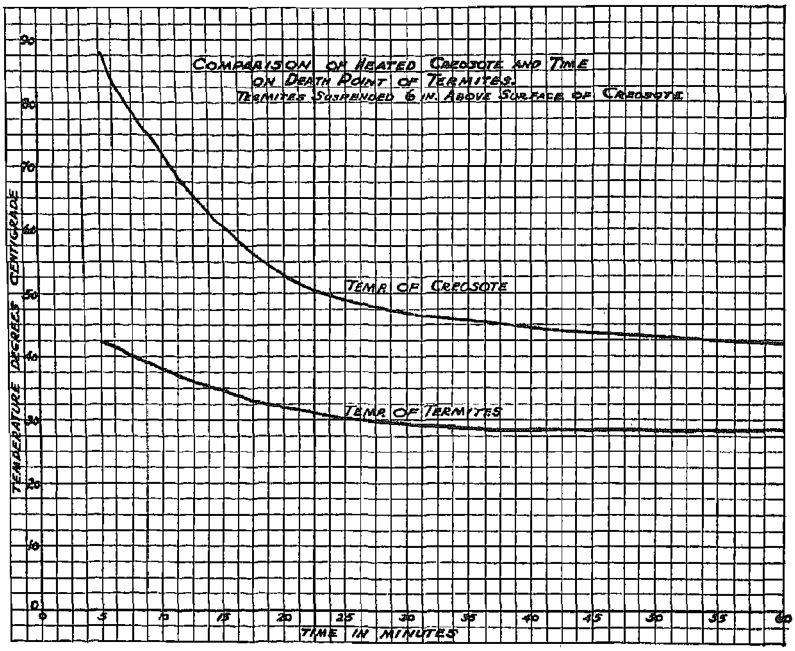

Fig. 116. Time required to kill termites suspended six inches above creosote which was heated to various temperatures. Experiments by Southern California Edison Company under the direction of Mr. Harold Michener, Timber Products Engineer.

To verify the conclusion that termites in an infested pole were not killed by heat during the full-length creosote treatment, termites in wire screen containers were sealed in holes bored into sound wood, not connected with galleries. Maximum thermometers included in each of these holes did not reach the thermal death point throughout the treatment. The poles were subjected to unusually severe treatment, being immersed in creosote at 195° F. (90° C.) for eight hours, and then allowed to stand in the creosote fifteen hours. After this treatment the termites were removed from the poles alive and in good condition. It was therefore concluded that the death of termites in the usual treatment was due to the creosote fumes which penetrated their galleries.

Creosote is toxic to the dry-wood termite and the creosote fumes are definitely repellent to it. No attack of creosote-treated material by dry-wood termites, other than in cases where the treated material had been so cut or damaged as to expose untreated wood, has come to the attention of the Committee. Indications are that pressure-treated creosoted wood is satisfactorily protected. The full-length open-tank treatment used on poles by the Southern California Edison Company has thus far given protection from the dry-wood termites. Whether creosote will prevent attacks on poles which have checked since treatment so as to expose untreated wood, remains to be seen.

Zinc chloride.—This material was proposed for wood preservation by Thomas Wade in 1815. The use of zinc chloride as a wood preservative became extensive with the development and patenting by Sir William Burnett in England in 1838 of a full-cell pressure process for its application. Zinc chloride for wood preservation was introduced into the United States about seventy years ago, and after about twenty-five years of experimentation came to be considered a standard wood preservative.

However, as creosote became cheaper and more uniform in quality its use increased, gradually replacing that of zinc chloride. During the period of the World War creosote became somewhat difficult to obtain. Its price increased to such an extent that many railway companies then using a creosote wood preservative treatment returned temporarily to the use of zinc chloride, which has been used extensively for the treatment of railroad ties, posts, poles, mine timber, and construction lumber. For these uses zinc chloride treated wood has shown a decided economic advantage over untreated wood, although service records have since shown the creosote treatment to be more permanent and wood so treated more economical for use in or on the ground. Nevertheless, zinc chloride is still used extensively where the odor, color, or staining tendency of the creosote is objectionable.

Several states have recently adopted specifications for zinc chloride treatment of highway posts and guard rails. For such uses it is realized that the water-soluble salt treatment is not so durable as creosote, but the zinc chloride treated wood can be painted for visibility. Zinc chloride treated wood is now used mostly for construction purposes when treated wood is desired for use above ground, or for use where a structure is to be painted. Textile mills, paper mills, and other industrial structures in which the conditions of moisture and warmth favor damage to wood by fungus are now using zinc chloride treated lumber extensively. The use of zinc chloride for the preservation of mine timbers has also increased in recent years. A heavy treatment of zinc chloride, *i. e.,* 2 pounds or more of salt per cubic foot (32 kg./cu. m.) of wood, shows considerable resistance to fire.

Zinc chloride is usually applied by the full-cell pressure-impregnation process adopted by the American Wood-Preservers' Association and given as specification 35C, "Standard Specification for the Preservative Treatment of Timber and Lumber by Pressure Process," in its *Manual of Recommended Practice.* This method is known as the Burnett Process. The full-cell method permits any desired final retention of zinc chloride by adjusting the strength

TABLE 29A

DATA ON TOXICITY OF WOOD PRESERVATIVES

Preservative	Douglas fir				Redwood				Sugar pine			
	Per cent preservative	Pounds per cubic foot	Days to kill 80 per cent	Days to kill 100 per cent	Per cent preservative	Pounds per cubic foot	Days to kill 80 per cent	Days to kill 100 per cent	Per cent preservative	Pounds per cubic foot	Days to kill 80 per cent	Days to kill 100 per cent
Untreated controls	....	....	110	>170	....	....	94	>160	....	....	105	>170
Ac-Zol, 10% solution	3.78	1.30	65	86	3.78	0.817	33	47	2.67	0.76	39	66
Anaconda Neutral, 3.44% solution	4.73	1.46	4	7	7.77	1.69	2	4	6.65	1.66	3	6
Bruce Preservative 5A	82.5	25.35	5	7	124.0	28.0	3	5	92.7	28.15	4	6
5B	38.6	13.20	8	12	67.8	13.16	6	10	52.1	14.42	7	9
5C	33.9	10.68	3	5	29.6	6.20	3	5	21.9	6.53	4	6
Creosote 100%, not dried	48.0	29.2	1	1	53.8	30.1	1	1	47.9	21.3	1	1
25%, not dried	10.7	6.3	1	2	13.42	7.53*	0	1	11.95	5.32*	3	4
10%, not dried	4.80*	2.92*	0	1	5.38*	3.01*	0	1	4.8*	2.13*	0	1
1%, not dried	0.48	0.292	24	43	0.54*	0.301*	12	33	0.48*	0.213*	41	75
0.50%, not dried	0.24*	0.0146*	63	93	0.27	0.015	62	74	0.24*	0.165*	31	163
0.25%, not dried	0.120*	0.0705*	54	118	0.134	0.075	52	85	0.119*	0.0533*	30	>160
Creosote 100%, dried at 50° C	42.8	25.2	1	3	44.0	20.6	2	3	32.0	11.3	4	5
25%, dried at 50° C	15.9	6.2	4	5	16.1	5.12	5	6	15.1	4.19	6	10
10%, dried at 50° C	4.28*	2.52*	6	12	4.4*	2.06*	7	10	3.2*	1.13*	9	17
1%, dried at 50° C	0.43	0.252	67	106	0.44	0.206	69	116	0.32*	0.113*	87	107
0.50%, dried at 50° C	0.214*	0.0126*	70	163	0.22	0.0103	>210	....	0.16*	0.056*	69	>210
0.25%, dried at 50° C	0.107*	0.063*	33	>210	0.110	0.0515	109	>210	0.08*	0.0282*	144	>210
Creosote 100%, air-dried	32.6	16.75	1	2	30.7	10.5	2	3	38.5	14.6	1	3
25%, air-dried	19.2	7.56	3	5	13.46	4.15	5	7	18.15	5.31	10	18
10%, air-dried	3.26*	1.67*	9	13	3.07*	1.05*	8	14	3.8*	1.46*	15	26
1%, air-dried	0.326	0.167	72	132	0.31	0.105	60	118	0.385*	0.146*	75	>210
0.50%, air-dried	0.163*	0.083*	60	117	0.153	0.052	52	77	0.19*	0.073*	77	105
0.25%, air-dried	0.0815*	0.042*	49	>213	0.077	0.026	49	>213	0.096*	0.0365*	121	>213

* Figures computed.

TABLE 29A—*(Concluded)*

Preservative	Douglas fir				Redwood				Sugar pine			
	Per cent preservative	Pounds per cubic foot	Days to kill 80 per cent	Days to kill 100 per cent	Per cent preservative	Pounds per cubic foot	Days to kill 80 per cent	Days to kill 100 per cent	Per cent preservative	Pounds per cubic foot	Days to kill 80 per cent	Days to kill 100 per cent
Halowax 2-26 I	56.9	38.3	7	10	66.46	47.0	7	11	59.15	40.2	8	11
1012 II	58.75	38.8	6	8	65.87	46.3	8	14	62.42	46.9	9	12
Lignophol	16.9	6.57	89	138	27.38	8.12	90	160	21.9	8.30	102	>170
Tanalith 2%	......	......	....	....	10.6	3.46	24	31	7.38	2.18	26	39
Zinc chloride, commercial, by Indiana Wood Preserving Company	5.02	1.73	84	139	6.48	2.65	118	139	6.68	3.32	106	>170
Zinc chloride 0.01%	0.0048	0.0018	49	61	0.0116	0.0017	111	134	0.0077	0.0020	82	112
0.02%	0.0099	0.0036	..	63	0.0188	0.0045	74	83	0.0175	0.0040	....	...
0.05%	0.032	0.0107	38	57	0.034	0.0084	53	70	0.033	0.0078	43	54
0.10%	0.050	0.022	83	112	0.096	0.022	68	78	0.101	0.025	53	61
0.25%	0.139	0.045	89	122	0.169	0.036	64	85	0.169	0.041	73	80
Zinc chloride 0.50%	0.197	......	149	167	0.317	0.074	100	118	0.328	0.067	90	129
0.75%	0.501	0.182	49	57	0.822	0.194	70	94	0.700	0.174	72	104
1.0%	0.627	0.201	90	116	0.930	0.218	97	128	0.234	1.06	78	105
2.0%	1.115	0.397	61	69	2.22	0.461	74	79	1.86	0.430	81	86
4.0%	1.98	0.668	90	95	3.80	0.828	55	67	4.56	1.03	90	134
Zinc-Meta-Arsenite 0.003%	0.0022	0.0051	74	142	0.0036	0.0051	88	135	0.0033	0.0051	63	83
0.025%	0.0162	0.041	48	79	0.0209	0.048	49	79	0.023	0.041	49	79
0.058%	0.0534	0.108	35	41	0.055	0.108	49	61	0.041	0.108	39	52
0.25%	0.172	0.481	37	48	0.276	0.491	60	72	0.265	0.496	31	49
0.50%	0.39	0.952	17	38	0.54	0.939	23	44	0.52	0.973	31	46
0.74%	0.46	1.315	10	16	0.69	1.187	10	15	0.64	1.280	....	....
0.98%	0.705	1.652	21	40	0.99	1.845	19	27	0.82	1.545	9	15
2.94%	1.89	4.74	11	16	3.42	5.93	11	16	2.92	4.64	6	9

of the treating solution. Some of the most frequently used weights of treatment are ½ pound, 1 pound, and 1½ pounds of zinc chloride per cubic foot (8, 16, and 24 kg./cu. m.) of treated wood. The treating solutions corresponding to these proportions are approximately 2 per cent, 4 per cent, and 5 per cent of zinc chloride in water.

The successful use of zinc chloride as a wood preservative led to the belief that it would be suitable for preventing damage by termites. However, in the United States termites have been generally recognized as an important factor in the life of treated wood only in the last few years, and consequently critical data on the subject are not available.

Field tests.—A fence post test carried on by the Santa Fe Railway Company at Cleveland, Texas, to study the value of several wood treatments gives some interesting data on zinc chloride in relation to termites. Eleven posts were given an open-tank treatment in 4.5 per cent zinc chloride solution. The average retention of preservative was 1.28 pounds of zinc chloride per cubic foot (20.5 kg./cu. m.). The posts were put under test in 1913, and were all found in excellent condition on inspection in 1927. The 1928 inspection showed some slight signs of decay, and in 1929 several posts showed decay, and in a few subterranean termites were working. Another group (fig. 117) of ten posts treated with a 2 per cent solution of zinc chloride by the open-tank method had a preservative retention of 0.471 pounds per cubic foot (7.54 kg./cu. m.). These posts were put under test in 1913 and all were in excellent condition at the 1919 inspection. Signs of decay were evident in 1920; then the damage increased until all the posts were affected by 1928. In 1928 the presence of termites was recognized and, although the live insects were found in only one post, their presence was suspected in others. The poles were inspected by digging down one side of them. They were not inspected further for termites, since for the purpose of this test the posts could not be further mutilated. At the 1930 inspection the posts had disappeared. Similar posts of southern pine, untreated, were set in 1913, but all were out of service by 1919. Their short life of six years shows the advantage of zinc chloride even when used in the soil.

In this same test were posts of Rocky Mountain type Douglas fir (New Mexico red spruce) treated with zinc chloride. This wood is difficult to treat and was prepared by full-cell pressure impregnation. Two test groups were prepared, one with ½ pound and the other with 1 pound of zinc chloride per cubic foot (8 and 16 kg./cu. m.). These posts were put under test in 1924, and both test groups had termites in them at the 1928 inspection.

A test of chemically treated fence posts in the Transvaal region of South Africa also included zinc chloride. The posts were treated with a 5 per cent solution of zinc chloride and retained 1.23 pounds per cubic foot (19.7 kg./cu. m.) of wood. The treatment gave protection against termite attack for only nineteen months, and the attack seemed to increase as time went on. The posts were materially reduced in strength; about 40 per cent of the volume of each post below ground level was devoured by termites, although the majority of the posts were still standing after seventy-four months' service.

These posts were attacked by termites above ground also, resulting in a grooved surface, which does not seriously impair the value of the posts. The average life of the untreated posts in this test was about thirty months.

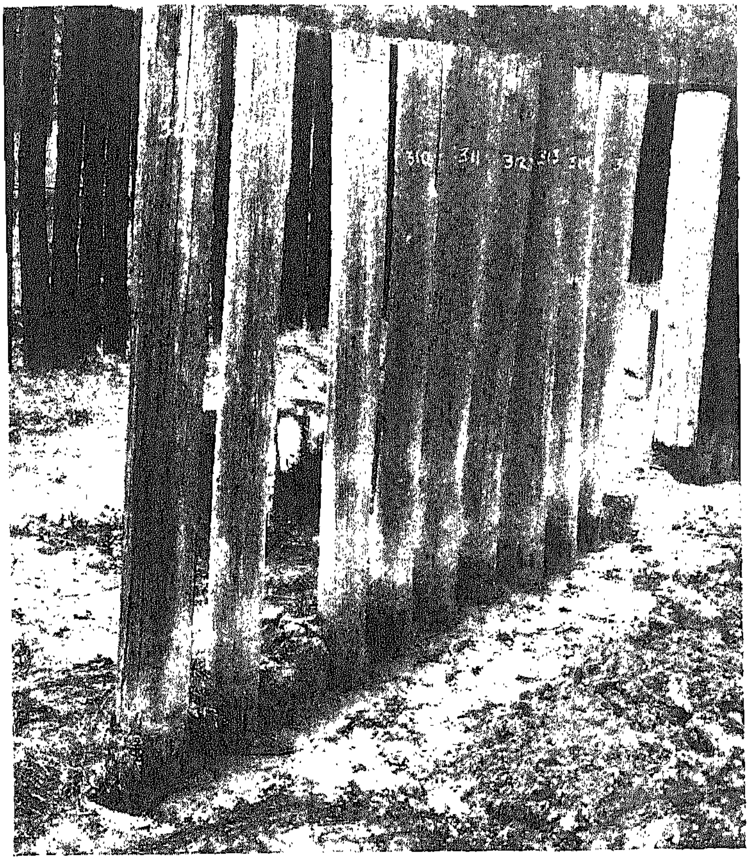

Fig. 117. Zinc chloride treated test fence posts. Southern sap pine posts 306 to 315, inclusive, treated with 0.47 pound of zinc chloride per cubic foot and placed October, 1913, at Cleveland, Texas, in a moist, warm climate favorable to decay. Photograph taken in 1928. Signs of decay were evident in 1920; then the damage increased until all of the posts were affected in 1928, at which time termites were found in one post and their presence was suspected in others. Experiments conducted by, and photograph furnished through the courtesy of the Atchison, Topeka, and Santa Fe Railway Company.

Inspections reported to the Committee by one of the railway companies in Oregon and Washington have shown test railroad ties treated with zinc chloride extensively damaged by the damp-wood termite, *Zootermopsis angusticollis.*

The San Diego Consolidated Gas and Electric Company, in order to test the value of zinc chloride against termite attack, soaked some insulator pins, crossarms, and pole stubs in a hot solution of zinc chloride. The test stubs, set in the ground, were destroyed by subterranean termites in three years. The insulator pins and crossarms were exposed to possible attack by the dry-wood termite only and have not been damaged in four years.

The tests of the U. S. Bureau of Entomology on Barro Colorado Island in Panama show that material treated with zinc chloride and set in the ground was attacked by termites within two years. The specimens were so badly damaged that the test was closed. Another group of specimens treated with a 5 per cent zinc chloride solution, also by impregnation, has been in the soil more than two and a half years without damage. For the latest report on these tests see pages 416–417. Wood pressure-treated with zinc chloride and exposed above ground on Barro Colorado Island has not been attacked in four and a half years.

The samples treated with zinc chloride in the International Termite Exposure Test were subjected to full-cell pressure impregnation and the average retention of preservative was about 1½ pounds per cubic foot (24 kg./cu. m.) of wood. All specimens in this test were set in the soil. Those exposed on Barro Colorado Island, Panama, showed 87.5 per cent destroyed and the other 12.5 per cent attacked by termites in twenty-five months' exposure. The specimens exposed in South Africa were entirely destroyed by termites in fourteen months. In Australia after one year of exposure 87.5 per cent of the zinc chloride treated samples were good, and 12.5 per cent were attacked by termites. The zinc chloride specimens in Hawaii were all good at the end of one year.

The service which can be expected from wood treated with zinc chloride, when used in the soil and exposed to termite damage, is somewhat longer than that from untreated wood. The tests of the toxicity of wood preservatives carried on by the Committee will throw further light on this subject (p. 380).

FIELD TESTS OF WOOD PRESERVATIVES

It was realized that no conclusive results of the value of wood preservatives in termite control could be gained from field tests during the three-year program of the Termite Investigations Committee. The literature shows that field tests of the resistance of preserved wood to termite attack have been carried on in many parts of the world, some of them over a period of sixteen years. It is seldom that results of more than a preliminary nature are obtained after two or three years' exposure.

Two important field tests designed specifically to test the effectiveness of preservatives in preventing termite damage were originated by Dr. T. E. Snyder, of the U. S. Department of Agriculture. One of these is the U. S. Department of Agriculture test at Barro Colorado Island, Panama, and the other is the International Termite Exposure Test, a cooperative test with similar specimens in Australia, Hawaii, Panama, and South Africa. The studies of the Termite Investigations Committee on wood preservatives were therefore confined to laboratory tests and field observations (chaps. 33 and 35).

A survey of several extensive tests of wood preservatives for preventing termite damage which have been made in different countries and climates shows wide variation in the relative values of the preservatives. This variation is no doubt due to the different methods of treatment used in the experiments, the variety of species of wood used (local woods being used in most instances), the difference in species of termites involved, and the wide variety of climatic conditions. The first comprehensive attempt to compare the effectiveness of preservatives when exposed to different species of termites in different parts of the world is now being made in the International Termite Exposure Test.

In the International Termite Exposure Test all specimens were 2 inches x 4 inches x 18 inches, made of air-seasoned sap pine (chiefly western yellow pine, *Pinus ponderosa*). The preservatives were applied by pressure-treatment processes at the U. S. Forest Products Laboratory at Madison, Wisconsin. Four complete sets of specimens were prepared, so that comparable tests could be made at four locations. Through the cooperation of four government institutions the sets of specimens were installed in four widely separated parts of the world where termite attack is severe.

Set No. 1 was sent to Barro Colorado Island in the Panama Canal Zone, where it was put under test by Mr. James Zetek of the Bureau of Entomology, U. S. Department of Agriculture, on August 10, 1928. Various other termite exposure tests are under way at this station, where many species of termites are active.

Set No. 2 was sent to the Division of Economic Entomology, Council for Scientific and Industrial Research, Australia, where it was installed by Mr. Gerald F. Hill, Senior Entomologist, during the period May 31 to July 18, 1929, in the Black Mountain Forest Reserve, Canberra, Federal Capital Territory. Most of the specimens were inserted into openings cut into the sides or summits of mounds made by termites. The termites quickly sealed the openings around the specimens, firmly fastening them into the walls of the mounds.

Set No. 3 was shipped to Dr. D. T. Fullaway, Entomologist, Board of Commissions of Agriculture and Forestry, Honolulu, Hawaii. The specimens were set out on April 27, 1929, in the grounds of the Board of Agriculture and Forestry, near the water front, where the soil-inhabiting termites *(Coptotermes)* are abundant.

Set No. 4 was shipped to the Research Branch, Forest Department, Union of South Africa, Pretoria. The specimens were installed on October 2, 1928 at Pienaars River Experiment Station by Mr. Nils B. Eckbo, Research Officer in Charge of Timber Investigations. Most of the specimens at this station were completely buried in the ground to put them out of sight so they would not be removed by the inhabitants for firewood. This station consists of 2¾ acres of fenced ground near Pienaars River Railway Station, Transvaal, at an altitude of 3,584 feet. The sandy loam soil bakes fairly hard during the dry season. A great many termite nests of different species are found in the area and untreated wood is destroyed rapidly.

The International Termite Exposure Test involves more preservatives, a wider range of exposure conditions, and a larger number of termite species than any single experiment previously attempted. The results of this test promise the first truly comparable information on the value of preservatives for preventing termite damage under the widely varying field conditions.

Ordinarily in an experiment of this kind, it is desirable to wait several years after the installation of the tests before publishing any results. Experience has shown that early indications may be greatly modified or even reversed as the exposure continues over a long period of years. Because of the number of people interested in the various preservatives, and because of the number of distant cooperators, there has been unusual demand for current information on this test. Consequently, the organizers of the experiment plan to publish the results of current inspections and the status of the experiment annually during the active life of the test. Hunt and Snyder, the authors of these reports (1930, 1931, 1932), warn against drawing conclusions on the relative effectiveness of different preservatives in the early stages of an experiment of this kind.

Some of the most extensive tests of wood preservatives, treated woods, and repellents for preventing damage by termites have been carried on in India. An experiment to differentiate between the values of various proprietary antiseptics was started in 1909 by R. S. Pearson of the Indian Forest Service. While Pearson's experiment was being carried on at Dehra Dun, a similar group of materials was put under test at Pusa, India, where the conditions of termite damage are somewhat different. Extensive experiments with treated railroad ties have also been carried on by the Indian Forest Service. Much of the damage to railroad ties in India has been due to termites. These tests of treated ties are therefore practically tests of the resistance of preserved wood to termite attack. It is of interest to note that little termite damage to railroad ties has been found in the western United States, in spite of extensive observations by cooperating railway companies and the personnel of the Commitee.

Another extensive series of tests was run in South Africa to test the effectiveness of preservative treatments and methods of applying them. These tests, which ran from 1906 to 1909, are known as the Simpson Experiment.

Oshima made a comprehensive investigation of termite-resistant materials on the Island of Formosa in which he tested a group of proprietary preservatives.

U. S. DEPARTMENT OF AGRICULTURE TESTS

The first experiment in the United States designed to test the value of preservatives and methods of treatment for protection from termite damage was made in 1912. These tests were conducted by the Bureau of Entomology, U. S. Department of Agriculture, from 1912 to 1922. Tests covering a wider group of preservative materials were begun in 1924 on Barro Colorado Island, Canal Zone, Panama, by the U. S. Department of Agriculture. Several progress reports on these tests have been issued, but none of the results have yet been published. As the preservatives employed are chiefly those sold and used in the United States, it seems advisable to publish here one of the progress reports (chap. 36).

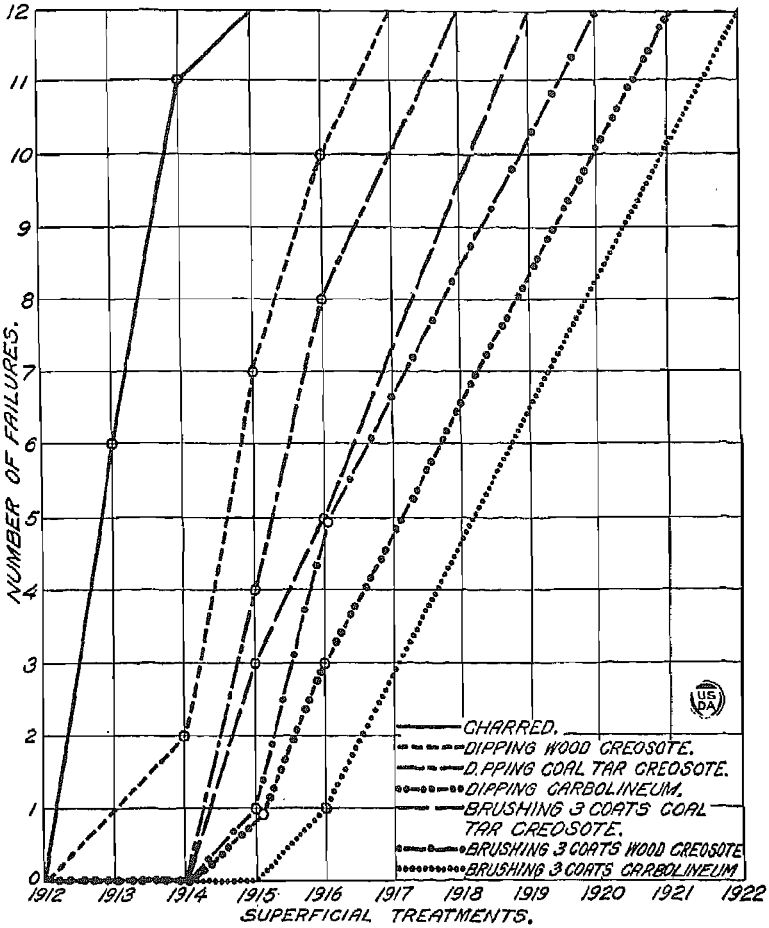

Fig. 118. Comparison of the relative resistance to attack by termites of chemical wood preservatives and methods of treatment, Falls Church, Virginia, 1912–1922. From *Department Bulletin No. 1231, U. S. Department of Agriculture*, reprinted by permission.

Judgment must be used in evaluating the data presented in the tables giving the summary of preliminary results of tests of wood preservatives on Barro Colorado Island. Conclusions of too general a nature are likely to be drawn from these results. A preservative material which has failed when used in the ground may be a good and suitable preservative for use above ground or for interior use. Materials, salts, and salt preservatives in particular, may be repellent or toxic to termites, but not suitable for exterior use unless protected by paint from leaching and weathering. The conditions in the test yard on Barro Colorado Island are severe with respect to leaching of preservatives. The location of this test plot was chosen by the U. S. Department of Agriculture with the belief that subterranean termite damage is as bad there as anywhere else in the world. The results of the tests on Barro Colorado Island should, of course, not be interpreted as affording any evidence as to resistance to dry-wood termite attack.

CHAPTER 35

COMMERCIAL PROPRIETARY PRESERVATIVES

BY

MERLE RANDALL AND THOMAS C. DOODY

We have considered separately a large number of preservative mixtures which are produced and marketed for the use of the individual builder or home owner. Most of such wood preservatives are complicated mixtures having some preservative value, usually made under a secret formula. They are intended for use as surface treatments rather than as pressure-impregnation treatments. We have termed this class of materials "proprietary preservatives." Complex mixtures devised primarily for termite control have also been included under this classification. The compounding required by these secret formulas is so complex that it is usually impracticable to obtain satisfactory chemical analyses for identification of the component materials. No attempt has been made to establish or certify the composition of these proprietary preservatives. However, we shall give as much information on the chemical compositions of the materials as we have been able to obtain from the manufacturers.

Proprietary preservatives are usually made for palliative treatments and are designed for application at the job. The commonly recommended methods of application are by brush treatment or by dipping the material to be protected in the preservative. Such treatments cannot be expected to be so permanent or satisfactory as pressure-impregnation treatments with recognized preservatives.

The general principles of protecting wood from fungus or termite damage are utilized both in the selection and application of these materials. The wood must be coated on all sides and ends so that destructive agencies cannot come in contact with untreated wood. The permanence of the protection depends to some extent, usually, upon the thickness of this coat of preserved wood, *i. e.,* on the amount of preservative used and its penetration into the wood. If the wood must be cut, or the treated surface broken in any way, a thorough treatment of the preservative should be applied to the freshly exposed surface of untreated wood.

In attempting to apply, by brush or spray, creosote or any other preservative to a structure already built, it is impossible to treat the joints in the woodwork satisfactorily. Although such a treatment cannot be called worthless, it must be remembered that the flat surfaces, which are easily treated, are not the most common points of termite attack. Termites frequently enter wood through crevices; where one timber comes in contact with another; or through small holes such as nail holes. These points can be thoroughly treated only at the time the structure is built and seldom receive any special protection when a completed structure is treated. Sprays or brush treatments of creosote or other preservatives will not eradicate termites already in the timber. They may be effective for some time as a preventive against new infestations where the surfaces of the wood are completely covered, but they seldom kill more than a few of the termites already in the wood. Preservative treatments of this nature may at first seem effective, because they will kill termites near the wood surfaces wherever the preservative comes in contact with the insects. Later examination usually shows the termites in the interior of the infested timbers unharmed.

In investigations made by the Committee of proprietary preservatives and termite "remedies," no attempt has been made to cover all of the materials offered for sale. A large number of such preservatives are available throughout the world. Some of them are on the market for only a few years and others are periodically changed in composition. Our tests of proprietary preservatives have covered principally the materials available in California, and a few other well known preservative mixtures. These have been studied under their trade names and in general represent the compositions of these proprietary materials as they were found on the market from 1928 to 1930. Some of these preservatives have since been changed either in name or in chemical composition. Several preservatives of strictly secret composition were sent us for trial, but no material of this type was tested.

DISCUSSION OF PRESERVATIVES TESTED

An-Fo No. 1, insecticide for termites, is an experimental product of the An-Fo Manufacturing Company of Oakland, California. It is intended as a preventive rather than as a cure for infested wood. The material is principally an oil and is emulsifiable in water. It is to be used in the ratio of 1 part to 10 or 15 parts of water, by painting or spraying the wood.

Avenarius Carbolineum was originated in Germany in 1876 by a chemist named Richard Avenarius. It was made from the heavy, high-boiling-point oils of creosote, which were filtered and chlorinated. The chlorination is said to decrease the volatility of the creosote oils and to increase the permanence of the preservative. *Avenarius Carbolineum, Arrow Brand,* is the American-made product of the Carbolineum Wood Preserving Company, Inc., Milwaukee, Wisconsin. The recommended methods of application of *Carbolineum* are by brushing, dipping, or spraying. The cost of this preservative is about 95 cents per gallon in 55-gallon drums.

Tests in India using *Avenarius Carbolineum* have shown seven and a half years of service from the treated wood as against three and one-fourth years for untreated wood. The U. S. Bureau of Entomology tests at Falls Church, Virginia, showed that *Carbolineum* gave slightly more satisfactory brush treatments than coal-tar creosote. The fence post test of the Santa Fe Railway at Cleveland, Texas, showed thirteen years of service from posts painted with *Carbolineum*. In the same test untreated posts lasted only six or seven years. *Avenarius Carbolineum* has also been tested by the San Diego Consolidated Gas and Electric Company. A few pole stubs brush-treated with hot *Avenarius Carbolineum* are apparently in good condition after three years' service. Another test group sprayed or brushed with *Carbolineum* has been described as giving fair results, and there has been no evidence of termite infestation in eight years of service.

Carbolic-Ol is a coal-tar creosote product of the Sherwin-Williams Paint Company. It has been tested in the field by the San Diego Consolidated Gas and Electric Company.

Carbosota and *Carbacide* are retailed by the W. P. Fuller Company and were tested with their cooperation.

Carbosota is the trade name of the grade 1 creosote oil of The Barrett Company. The recommended method of application is by hot and cold open-tank treatment. For general purposes a brush application is suggested. The retail price in small amounts is about 50 cents per gallon.

The value of *Carbosota* for killing termites in infested wood was tested by the Committee. It was applied to three red cedar pole stubs infested with the dry-wood termite, *Kalotermes minor,* by brush application. These stubs, 8 to 10 inches (20 to 25 cm.) in diameter and about 10 feet (3 m.) long, took 1½ gallons (5.6 l.) of *Carbosota* each. Inspection 9 weeks after treatment showed some dead termites in the sapwood where the preservative had reached them, but most of the insects were in the heartwood unharmed by the treatment.

Carbacide is a preservative blended of coal-tar creosote and petroleum oils. The lighter creosote oils, which contain a higher percentage of tar acids, are used, and the blended preservative has about 10 per cent tar acids. The price of *Carbacide* ranges from approximately 75 cents to $1.00 per gallon, according to the quantity purchased. This product was tested by the San Diego Consolidated Gas and Electric Company, applied to pole stubs by brush treatment. It was reported to be about equivalent to a creosote brush treatment.

Carbacide was tested by the Committee as a termite eradicator on pole stubs infested with the dry-wood termite, *Kalotermes minor*. It took about 1 gallon (3.79 l.) of material to give each pole stub, about 10 inches (25 cm.) in diameter and 10 feet (3 m.) long, a thorough brush treatment. Inspection nine weeks after treatment showed only a few dead termites in the sapwood, where the preservative had reached them. Many live insects were found in the heartwood and within a fraction of an inch of the treated pole surface. These tests confirm the fact that surface treatments do not eradicate termites in infested timber.

Cabot's Conservo and *105 Oil* are preservative materials sold by Samuel Cabot, Inc., of Boston, Massachusetts. Both preservatives are coal-tar distillation products. *Cabot's Conservo* is a heavy distillate, vertical tar, consisting mostly of the higher boiling fractions of coal-tar creosote. It contains about 10 per cent tar acids. We have had no experience in the field with this preservative. *Cabot's 105 Oil* is a lighter coal-tar distillate, containing 16 to 20 per cent tar acids. This lighter oil is not so permanent as the *Conservo* wood preservative, and is used principally as an insect repellent. The application recommended for these preservatives is by brushing, dipping, or soaking.

The toxicities of two creosote *shingle stains* manufactured by Samuel Cabot, Inc., were tested. These stains were designated *No. 222* (black) and *No. 301* (green). We were unable to get the exact composition of these shingle stains, but the usual composition of creosote shingle stains is about 2 per cent pigment and 98 per cent vehicle. The vehicle is about 50 per cent creosote and 50 per cent linseed oil, with a small percentage of drier. The creosote used consists of the light oils which penetrate more readily, but are not so permanent.

California Road Oil is a petroleum distillate product which is customarily used for killing weeds and laying dust on roads. In 1929 the distributors, the California Road Oil Service Company, Wilmington, California, discovered that the oil is toxic to termites. The grade of *California Road Oil* used for termite control is slightly heavier than kerosene or distillate. Due to the nature of the cracking process used in the production of this oil it contains aromatic compounds and is said to have some phenols. The toxicity of the oil was tested in the laboratory.

Field tests of the *California Road Oil* for killing termites in infested wood were made in 1929. Two red cedar poles infested with the dry-wood termite, *Kalotermes minor,* were given thorough brush and spray treatments to a height, respectively, of 5 and 10 feet (1.5 and 3 m.) above ground. About 1 and 2 gallons (3.79 and 7.5 l.) of oil, respectively, were used on each pole. The poles were removed and inspected about six months after treatment. The termites above the treated section of the pole were not affected. The oil had penetrated well into most of the sapwood in the treated sections. Dead termites were found in the galleries in the sapwood, but a few live ones were also found there. Many live termites were found in the heartwood, where the oil had not penetrated. The oil was quite toxic, not permanent when exposed to weather conditions above ground, and showed decreased effectiveness in six months.

Two poles infested with the subterranean termite, *Reticulitermes hesperus,* were treated. *California Road Oil* was poured into a shallow trench dug around the butt of the poles and in holes 18 inches (46 cm.) deep drilled in the soil down the sides. Ten gallons (37.8 l.) of oil were used in each case. One pole was badly rotted below ground line and accepted the treatment readily. No live termites could be found there six months after treatment. The butt of the other pole was sound and it had been previously attacked by termites only on the surface. After treatment *California Road Oil* was evident in the surface wood to a depth of 2 feet (60 cm.) below ground. There were no live subterranean termites in that part of the pole butt. Below that the insects were not affected.

California Road Oil is a petroleum product with a reported high flash-point, and the vapor from it is said to be non-explosive. However, if it is used for termite control the inflammability of the product should be considered.

Ceasrot Concentrated is manufactured by Bitulac, Ltd., of Newcastle-upon-Tyne, England. The material is recommended for application by brush treatment, either as furnished or diluted in water. The principal toxic ingredient is a soluble arsenical, but it also contains about 2 per cent of cresylic acid. The toxicity was tested and the preservative found strongly poisonous to termites, but we have had no experience with the permanence of *Ceasrot Concentrated* for practical use.

Columbia Wood Preservative is manufactured and distributed by the Columbia Wood and Metal Preservative Company of Berkeley, California. The preservative is viscous at ordinary temperatures and is recommended for application hot by brushing or dipping. The heavy material is a gum base with creosote as the antiseptic ingredient. A light coal-tar creosote of high tar-acid content is used and the preservative has a slightly higher tar-acid content than average grades of creosote. The preservative sells for about 80 cents per gallon f. o. b. Berkeley. The material has been used extensively but we have not obtained any observations on it in the field. The manufacturers recommend *Columbia Wood Preservative* as a seal over a creosote treatment to prevent loss of the lighter coal-tar oils when used in hot climates. *Columbia Wood Preservative* is also suggested for application to creosote treated wood which has checked so badly as to expose untreated wood.

The toxicity of a special formula of *Columbia Wood Preservative* for preventing termite damage was tested in the laboratory. This formula had a small percentage of copper soap added to the regular preservative.

Cuprinol is a wood preservative manufactured by A. S. Kymeia of Copenhagen, Denmark. We obtained this preservative through the Davis Hardwood Company of San Francisco, who represent the East Asiatic Company, Inc. The composition of *Cuprinol* is given as 55 per cent volatile solvents, 45 per cent "copper soap," probably copper oleate. For the treatment of wood, *Cuprinol* is recommended diluted with equal parts of kerosene or light paraffin distillate. It is applied by brush or spray treatment. We did not find *Cuprinol* used, in our field experience with preservatives.

Eastman No-D-K is a wood creosote made by the Tennessee Eastman Corporation of Kingsport, Tennessee. This material was at one time used extensively in the butt-treatment of telephone poles by brush application. Tests of the U. S. Bureau of Entomology at Panama show timber brush-treated with *Eastman No-D-K* was attacked after being in the soil five years and two months.

Fishoilene is oil made primarily for application to iron or steel, but has been proposed by the manufacturer for termite control because of its penetrating power. It is made by the Pacific Fishoilene Company of Los Angeles. *Fishoilene* is a combination of fish oil and China wood oil. It is said to have high penetrating power and oxidizes to a tough protective film. It sells for about $2.75 per gallon in barrel lots. As far as we know, *Fishoilene* has had no practical use for termite control.

International Wood Preservative is the product of the International Wood Preservative Company, Oakland, California. It is manufactured under U. S.

Patent No. 1,690,390. The preservative is made for commercial use, but as it is not yet available in treated timber and poles it has been included with the proprietary materials. *International Wood Preservative* is composed of ten ingredients: Paraffin oil, naphthalene? (cleaners' naphtha used), benzol light creosote, heavy creosote, oil of coal-tar, cement, hydrated lime, sulfur, and Paris green. The purpose of the mixture is to produce from the creosote and volatile solvents a highly penetrating preservative, and have the solids and heavy ingredients dry to a protective shell on the wood surface, which will prevent loss of toxic ingredients by leaching and weathering. *International Wood Preservative* is applied cold by twenty-four hour immersion. The cost is approximately 50 cents per gallon.

One test of the penetrating power of *International Wood Preservative* was made in the pole yard of the Southern California Edison Company in Alhambra, California. A section of a new western red cedar pole, 12 inches (30 cm.) in diameter, was soaked in the preservative for about nineteen hours. A complete penetration of the sapwood, about 1 inch (2.5 cm.) thick, was obtained. The next section of the same pole was soaked in cold grade 1 creosote for the same length of time and showed equally good penetration.

International Wood Preservative was also tested as a means of exterminating termites in infested wood. A red cedar pole infested by the dry-wood termite, *Kalotermes minor*, was brush-treated with *International Wood Preservative* from the ground line to a height of 10 feet (3 m.), using ½ gallon (1.9 l.) of preservative. The pole was removed and inspected six months after treatment. Live termites were found in it near the ground line and above within 1 inch (2.5 cm.) of the treated wood. The penetration of preservative showed about ⅛ inch (0.3 cm.).

Another pole infested above ground with the dry-wood termite and below ground with the subterranean termite was treated with *International Wood Preservative*. The loose sapwood infested with termites was cut off the pole from about 1 foot (30 cm.) below ground to 3 feet (90 cm.) above ground. A water-tight metal jacket was clamped around the pole at this point, being sealed at the bottom with a rubber dam and putty. About 5 gallons (18.9 l.) of *International Wood Preservative* was poured into this jacket and allowed to remain around the pole for twenty-one hours. When the jacket was removed about 2½ gallons (9.5 l.) of oil remained, having run into the trench around the pole, and soaked down the pole butt. The pole was removed for inspection six months after treatment. The preservative which ran down the pole butt had thoroughly coated it and soaked into the rotted wood. No live subterranean termites could be found. The average penetration of the oil in the treated zone was about ¼ inch (0.6 cm.), which was the thickness of the remaining sapwood. Live dry-wood termites were found throughout the pole from the ground line to the top.

The U. S. Bureau of Entomology tests in Panama show wood treated by immersion in *International Wood Preservative* was attacked by termites after being in the soil five years and five months. For the latest report on these tests see pages 416–417.

Inwood is made for the sealing and finishing of floors. It is distributed through Hills-Hamilton Company of Davis Street, San Francisco. The price of *Inwood* in 5-gallon lots is about $6.25 per gallon. We have not been able to learn the definite composition of *Inwood*, but have been told it is made by blending linseed oil with gums and waxes. The material is applied to flooring in a generous brush coat, the excess removed after a few hours, and the floor polished when thoroughly dry. The manufacturers claim that to produce a termite-proof floor the *Inwood* must penetrate the flooring completely.

Letteny is a wood preservative material manufactured by The Northeastern Company of Cambridge, Massachusetts. It is a coal-tar distillate composed of the high boiling coal-tar creosote fractions. The price quoted on this material by Marshall Dill, manufacturers agent at San Francisco, was 65 cents per gallon.

Lignophol is a product made by L. Sonneborn Sons, Inc. of New York. It is composed of natural oils, gums, and resins, extracted from wood, and has been discussed in chapter 34.

Ligni-Salvor is a blended preservative made in Germany. It is handled in the United States by Pfaltz and Bauer, Inc., New York. It is made to combine the properties of a preservative and a finishing material. The composition is creosote oil blended with other oils for waterproofing and to allow finishing of the treated surface. We have found no specific use of *Ligni-Salvor* against termites and our only experiments with it were for comparison of its toxic power. It is applied by dipping or brush treatment. Three coats are recommended, with forty-eight-hour drying periods between them.

Locustine is a preservative material which had considerable use many years ago. It is again available through the D and M Tile Company of Los Angeles. It is said to consist of non-volatile petroleum products blended with animal and marine oils to which strong antiseptics are added. *Locustine* brush-treated posts in the Santa Fe Railway Company test at Cleveland, Texas, failed after seven years, as against six years for untreated material.

Peach Pit Tar is a by-product of the processes of Western Industries Company of San Francisco. The material is of the nature of a wood-tar produced from the destructive distillation of peach and apricot pits. The tar contains 8 to 12 per cent water, 2 to 4 per cent free acetic acid, and some esters of cresols and xylenols. The material has not been used for wood preservation but is proposed for that purpose.

The Petro-Creoleum Corporation of San Diego, California, has sixteen preservatives manufactured under secret formulas. The toxicities of four of these products were investigated in the laboratory, and tests of one of them made by the San Diego Consolidated Gas and Electric Company were observed.

Petro-Creoleum No. 11 is composed chiefly of a mixture of rosin, wax, and creosote, with small percentages of naphthalene and phenol for toxicity. At room temperature it is a solid wax. This preservative is made for piling and marine timber and must be applied hot by the open-tank or pressure treatment.

Petro-Creoleum No. 14 is chiefly creosote, paraffin base oil, and distillate, with small percentages of naphthalene and phenol. This material is applicable by brush or spray to timbers in use.

Petro-Creoleum No. 15 consists of paraffin base oil, distillate, naphthalene, and phenol. This preservative is much like formula No. 14 in physical characteristics and is used in the same manner.

Petro-Creoleum No. 16 is a slightly different blend of engine distillate, paraffin oil, naphthalene, and phenol. Two-foot (60 cm.) sections of poles infested with the dry-wood termite were immersed in a bath of this mixture at 140° F. (60° C.) for four hours. These pole sections were inspected about a year later and all the termites in the infested wood had been killed. It was noticed that the inflammability of the wood was greatly increased by treatment.

Phinotas Oil is a product of the Phinotas Chemical Company, Inc., Front Street, New York City. It is evidently a wood distillation product, containing cresol. To our knowledge there has been only one report of the use of *Phinotas Oil* for termite control. It was used diluted with 20 parts of water to 1 of the oil for application to soil infested with a subterranean termite. The experimenters considered this soil treatment with *Phinotas Oil* effective and propose it for further testing.

Potassium Xanthate has not been used in termite control work, but has recently been tested by de Ong and Tyler (1928) as a possible material for the control of insects in soil.

Premite No. 2 was formerly known as Prewood. It is a hardwood creosote produced by The Sullivan Company of Memphis, Tennessee, for wood preservation. There is also a *Premite No. 1* which is a coal-tar creosote and should not be confused with *Premite No. 2*.

Preservitol is a wood creosote obtained from the destructive distillation of hardwood. It is distributed through the Heyden Chemical Corporation, New York City. It comes in two grades: *Preservitol Regular* is composed of the high boiling fractions isolated from hardwood tar. *Preservitol Special* consists of the regular product with 15 to 20 per cent of phenolic compounds obtained from wood distillation added. These products may be applied by brush treatment, but are recommended for open-tank or pressure impregnation.

Preservitol Regular was tested in the field by the San Diego Consolidated Gas and Electric Company in 1925. Pole stubs brush-treated with *Preservitol* showed failures after two years. A heavier grade of *Preservitol* obtained in 1926 and applied in a heavy brush treatment has shown only a few failures in five years.

Tests of the U. S. Bureau of Entomology have shown that wood creosote gives a less permanent preservative treatment than coal-tar creosote. Wood creosote is often used, however, because of its less objectionable odor.

Protexwood is a wood creosote product obtained principally from the destructive distillation of pine wood. It is made and sold by The Termiteol Corporation of New Orleans.

Roger's Gas is a product of McEverlast, Inc., of Los Angeles made for the control of termite infestations by fumigation. *Roger's Gas* is sold as a liquid composed of carbon bisulfide, carbon tetrachloride, pine oil, paradichlorobenzene, and phenol. The carbon bisulfide and carbon tetrachloride would act only as fumigants, and, since they are highly volatile, would have no permanence. The purpose of the other materials in the compound is to leave some permanent protection after the so-called "gassing" treatment. The toxicity of fumigating materials and the value of fumigation treatments for control of termite infestations is considered fully in chapter 39. The toxicity of *Roger's Gas* as investigated in these tests deals with the protective value of the treatment after the more volatile constituents have disappeared.

Ryite Termicide is a product of the Republic Creosoting Company of Indianapolis, Indiana. It is a special blend of coal-tar creosote distillation fractions for termite control work. This oil was brought on the market in 1930 and no extensive use of it has been reported.

Spirittine Chemically Treated Pine Oil and *Spirittine Insect Destroyer* are two of the products of the Spirittine Chemical Company of Wilmington, N. C. *Spirittine Chemically Treated Pine Oil* is a material made specifically for the destruction of termites and other wood-boring insects. We understand this material is made from *Spirittine Wood Preservative* by the addition of chemicals destructive to insect life. The composition of the material, therefore, is mainly 50 per cent pine wood creosote and 50 per cent paraffin oils. The manufacturer recommends the application of *Spirittine Chemically Treated Pine Oil* to sills and substructures of buildings by spray treatment. The price is about 75 cents per gallon.

Spirittine Insect Destroyer is made for the control of insect infestations. The product has pyrethrum extract and paradichlorobenzene in a light solvent oil. The odor is not unpleasant. The solvent oil would probably have only slight fumigating action, but the other materials give the product some permanence. The toxicity tests made by the Committee were concerned only with this more lasting protection. The cost of this material is $2.00 per gallon.

Solignum is a widely known preservative manufactured by Solignum Ltd. of London, England. It was handled on the Pacific Coast by McEverlast, Inc. of Los Angeles, California, and was sold by them at about $2.00 per gallon in small lots and $1.25 per gallon in 10-drum lots. The principal constituents of *Solignum* are the high-boiling oils of coal-tar creosote. It is supposed to have a toxic chemical compounded with these, but its identity has not been established. The recommended application is by brushing, spraying, or dipping.

Tests of the Forest Research Institute in India have shown *Solignum* one of the most satisfactory proprietary preservatives tested there. Test pieces of wood soaked in *Solignum* and exposed to attack by both rot and termites lasted nine and a half years as again five years for the untreated control specimens. *Solignum* has been tested by several government agencies in tropical countries for preventing termite damage. The protection afforded varied greatly with the method of treatment and the ease of treating the species of wood used. In the reports on these comparative tests *Solignum* is considered, with other coal-tar distillation products, to be among the more satisfactory materials for preventing termite damage. With its introduction upon the Pacific Coast *Solignum* was used extensively by the termite control companies in southern California. It was intended as a preservative for preventing termite damage and as a remedy for killing termites in infested wood. The most extensive use of *Solignum* was by spray application to wood infested with the dry-wood termite.

The experience of the Committee has shown that preservatives applied to the surface of infested timber do not kill the termites within it. An inspection of wood sprayed with *Solignum* in houses treated by termite control companies, and a few small scale experiments showed that *Solignum,* also, does not kill the termites in the wood. Two red cedar pole stubs about 10 inches (25 cm.) in diameter and 8 feet (2.4 m.) long, infested with the dry-wood termite, were treated with *Solignum.* It was applied hot; one stub was sprayed generously and the other thoroughly brush-treated, using 1 gallon (3.79 l.) of *Solignum* on each. These stubs were cut open for inspection ten weeks after treatment. Some dead termites were found in the sapwood where the preservative or the fumes from it had reached them. A few live termites were also found in the sapwood, but most of the insects were in the heartwood unharmed.

This led to a more extensive series of tests in cooperation with McEverlast, Inc., local distributors of *Solignum.* This series of tests was also performed on well seasoned pole sections infested with the dry-wood termite. Two pole sections were sprayed with cold *Solignum;* two more were treated by pouring *Solignum* into holes bored into the infested wood every 12 inches (30 cm.); another two were treated by a combination of spraying and pouring the preservative into holes bored into the wood; two other sections were butt-treated by soaking in cold *Solignum* for one hour; and four more were soaked in cold *Solignum* for three hours. These test pieces were cut up for inspection seven weeks after treatment. The spray treatment showed a penetration of about ⅛ inch (0.3 cm.), and live termites were plentiful even within ⅛ inch (0.3 cm.) of the treated wood. The *Solignum* poured into holes bored into the infested wood killed only those termites with which it came in contact. The treatment combining the two methods above was more effective than either alone, but live termites were still found. The butt treatment for one hour gave from ⅛ inch (0.3 cm.) to a full sapwood penetration, and the three hour soaking gave a full sapwood penetration, but neither treatment affected the termites in the heartwood.

Termiteol is a product made particularly for termite control by The Termiteol Corporation of New Orleans, Louisiana. The manufacturers also operate termite control companies for the treatment of termite infestations. *Termiteol* is reported to have a pine oil base, probably a pine-wood creosote, with added chemicals of recognized toxicity to insects. The preservative is recommended for spray treatment, but is also used as a brush treatment. The manufacturers recommend its use on new material at the time of construction, but the termite control companies also apply it to structures already built.

TABLE 30

TOXICITY TESTS OF COMMERCIAL PROPRIETARY PRESERVATIVES ON THE DAMP-WOOD TERMITES

Chemical	Per cent preservative by weight after drying	80 per cent death (days)	100 per cent death (days)	Amount of eating
An-Fo	15.28	4	7	None
Avenarius Carbolineum	40.26	4	5	None
Cabot's Shingle Stain No. 301	13.4	4	6	None
Cabot's Shingle Stain No. 222	24.1	5	6	Small piece chewed near edge
Creosote Shingle Stain (dried six months)	....	41	68	Slight amount
Cabot's Wood Preservative	32.85	4	7	None
California Road Oil	19.70	2	3	None
Carbolic-Ol	19.68	5	8	None
Ceasrot	45.17	4	5	None
Coal-Tar Creosote (grade 1)	28.90	1	2	None
Columbia Wood Preservative	67.7	8	15	None
Cuprinol	43.0	21	62	Several places chewed
Cuprinol 50% solution in petroleum ether	35.9	8	13	Slight chewing
Eastman No-D-K	47.0	3	5	None
Fishoilene	....	30	41	Feeding
International Wood Preservative	43.5	2	4	None
Inwood	50.1	3	4	None
Letteny Wood Preservative	43.8	4	8	None
Lignophol, Natural	35.91	17	30	Feeding
Ligni-Salvor	27.26	9	11	Extensive feeding
Locustine	47.8	26	30	Feeding
Peach Pit Tar	40.9	8	10	Feeding
Petro-Creoleum No. 11	44.44	19	24	Feeding
Petro-Creoleum No. 14	....	28	58	Feeding
Petro-Creoleum No. 15	26.04	42	64	Feeding
Petro-Creoleum No. 16	18.80	28	35	Feeding
Phinotas Oil	11.1	1	3	None
Phinotas Oil 5% in water	1.6	1	4	None
Potassium xanthate	9.5	2	5	None
Potassium xanthate	6.4	3	9	Slight feeding
Potassium xanthate	2.5	24	34	Feeding
Premite No. 2	12.5	2	3	None
Preservitol Regular	19.64	23	30	Feeding
Preservitol Special	14.40	15	18	Feeding
Protexwood	19.3	16	32	Feeding
Roger's Gas	....	9	12	Feeding
Ryite Termicide	26.50	11	13	Slight feeding
Spirittine Chemically Treated Pine Oil	2.05	11	23	Feeding
Spirittine Insect Destroyer	....	5	7	Feeding
Solignum	24.23	3	5	Slight feeding
Solignum (dried 40 hours at 70° C.)	....	8	10	
Sodium arsenite 10%	18.58	2	7	None
Sodium arsenite 5%	53.37	1	3	None
Termiteol	28.8	17	34	Feeding
Termitol	54.3	12	20	Slightly chewed
Termitol (diluted as recommended by manufacturer)	4.8	16	51	Feeding
Termol	29.5	9	16	Feeding
Tetrachlorphenol	14.3	1	1	None
Zinc chloride	55.75	14	18	Feeding

TABLE 31

TOXICITY TESTS OF COMMERCIAL PROPRIETARY PRESERVATIVES ON THE DRY-WOOD TERMITES

Preservative	Douglas fir				Redwood				Pine			
	Per cent preservative	Pounds per cubic foot	Days to kill 80 per cent	Days to kill 100 per cent	Per cent preservative	Pounds per cubic foot	Days to kill 80 per cent	Days to kill 100 per cent	Per cent preservative	Pounds per cubic foot	Days to kill 80 per cent	Days to kill 100 per cent
Avenarius Carbolineum	......	......	1	2	......	......	3	4	......	......	1	2
Cabot's Shingle Stain												
No. 301 green	3.2	1.1	12	17	4.5	1.2	16	24	4.4	1.3	14	60
No. 222 black	2.5	0.88	6	8	5.9	1.7	4	8	5.6	1.8	8	10
Carbolic-Ol 19.68%	4.83	1.78	3	4	10.8	2.85	3	6	8.61	2.62	3	5
Ceasrot 45.1%	15.0	5.40	4	5	37.0	11.82	3	5	23.5	6.34	6	8
Coal-Tar Creosote, grade 1	7.80	2.77	2	3	11.16	3.24	2	3	12.97	4.30	2	3
Columbia Wood Preservative:												
soaked in hot preservative	......	......	3	6	......	......	2	6	......	......	4	6
2 coats brush treated	......	......	7	10	......	......	4	6	......	......	6	8
Cuprinol	......	......	46	88	......	......	40	85	......	......	76	95
Cuprinol diluted with 50% petroleum ether	4.1	1.32	69	88	6.7	1.78	92	106	4.7	1.41	33	89
Eastman No-D-K	12.3	4.75	4	6	15.2	5.15	3	5	15.6	5.55	5	7
Fishoilene 40.02%	19.5	7.16	28	68	31.2	9.05	36	78	27.2	8.30	18	35
International Wood Preservative	14.2	5.14	5	6	16.1	5.34	4	7	20 7	7.40	4	5
Inwood	8.46	3.18	43	>156	15.0	4.75	87	>156	15.9	5.55	100	>156
Letteny	16.6	5.65	2	3	21.2	7.80	2	3	23.9	9.10	2	4
Ligni-Salvor 27.26%	19.4	5.56	3	5	24.4	7.16	2	4	6.03	2.43	3	5
Locustine	11.1	4.24	17	38	16.7	5.35	29	38	16.4	6.15	25	35
Peach Pit Tar—2 coat brush treatment	......	......	17	24	......	......	12	15	......	......	22	37
Premite No. 2 brush treated	4.7	1.50	63	98	1.47	0.63	53	75	4.5	1.37	51	94
Preservitol Regular 19.64%	11.95	4.40	1	2	24.5	7.0	2	3	26.1	7.72	1	2
Preservitol Special 14.40%	20.07	9.39	1	2	24.1	6.80	1	2	29.4	9.15	1	2
Protexwood	......	......	39	>180	......	......	82	117	......	......	87	100
Roger's Gas	......	......	25	35	......	......	33	35	......	......	11	17
Ryite 26.50%	16.85	6.78	2	3	26.2	8.02	3	5	23.6	6.37	2	3
Solignum	......	......	1	1	......	......	2	2	......	......	2	4
Termiteol	......	......	45	71	......	......	39	52	......	......	33	65
Termitol 25% in water	4.58	1.50	16	25	4.1	1.12	63	92	3.88	1.12	30	89
Termitol (undiluted)	......	......	35	45	......	......	43	61	......	......	29	42
Termol	......	......	22	27	......	......	19	42	......	......	40	56
Untreated	......	......	110	>170	......	......	94	>160	......	......	105	>170

Termitol is a material to be used for termite extermination, made by the Wood Chemical Products Company, Jacksonville, Florida. The material tested by the Committee was obtained from the manufacturers in 1930 and was then considered as experimental. *Termitol* is made chiefly from a special heavy grade of pine tar oil with small amounts of rosin, copper sulfate, caustic soda, and water. This is diluted for use with 1 part of the mixture to 4 parts of water. The manufacturers estimate that *Termitol* can be sold in drum lots at 50 cents per gallon f. o. b. Jacksonville. Since the testing of the *Termitol* of 1930 two samples of an improved product have been submitted for investigation. Our series of toxicity tests was completed before the arrival of these samples.

Termol is made in Japan by the Camphor Bureau of the Government. The toxic material, which is dissolved in a light petroleum oil, is reported to be the sesquiterpene alcohols obtained from camphor green oil. Wood is treated with *Termol* by impregnation or by immersion. *Termol* was tested as an exterminator for the dry-wood termite in infested poles by the San Diego Consolidated Gas and Electric Company. A heavy brush treatment had no effect on the termites in the interior of the infested wood. There was no visible evidence of the treatment after two years of exposure of the test stubs to weathering. *Termol* is reported used extensively and effectively for preventing termite damage in Japan and in Hawaii.

Tetrachlorphenol is an organic chemical manufactured by the Dow Chemical Company, Midland, Michigan. Unpublished results of tests of this material on wood-destroying fungi by the manufacturers showed promise, so *Tetrachlorphenol* was included in the tests on termites. This chemical has a pungent and penetrating odor, and is said to have considerable permanence. It has only a slight solubility in water, but was used in our tests as a colloidal emulsion containing 5 per cent *Tetrachlorphenol* in water. The colloidal *Tetrachlorphenol* was obtained from H. K. Patch, a manufacturer of colloidal products in Los Angeles. The material came as a pasty colloidal mass containing 33 per cent of *Tetrachlorphenol* as the only active ingredient.

TOXICITY TESTS

Tests of the toxicity of proprietary preservatives and termite repellents were made with the damp-wood termite, *Zootermopsis angusticollis*, and with the dry-wood termite, *Kalotermes minor*. These two series of tests support other work which shows that chemicals and preservatives toxic to one species of termite are also effective with other species, even though the life habits of the insects vary widely. These tests on treatments with proprietary preservatives allow a comparison of these products with commercial wood preservative treatments and with pure chemicals which were tested in a similar manner. They show not only the overall effectiveness of the treatments, but give, also, information on their repellency.

Damp-wood termite toxicity tests.—The test specimens for the damp-wood termite toxicity tests were pieces of filter paper 15 cm. in diameter, thoroughly brush-treated with the preservative to be tested. These were allowed to air-dry, lying flat, for eight to ten weeks. When the papers were suspended for drying the preservative concentrated at the lower edge. Drying the papers flat gave an even distribution of preservative except with preservatives carried in light volatile solvents, which showed slight concentrations of preservative at the edge of the paper. Only the central 10 cm. portion of these treated papers was used in the toxicity tests. The amount of preservative in the paper was determined by weighing it first before treatment and then after drying. Some of the preservatives in very light solvents dissolved substances from the paper and showed a negative computed retention of preservative.

The centers of four treated papers were put in a 10 cm. Petri dish with twenty-five full grown nymphs of the damp-wood termite, *Zootermopsis angusticollis.* One square inch (6.5 sq. cm.) of waxed paper, on which a few drops of water were maintained, was placed on top of the treated papers. This gave the termites all the water they required, but kept it from coming in contact with the treated papers. These termites were so greedy for water that they often had to be removed from the drops to prevent their drowning. Daily observations were made on the number of termites remaining alive. The records are summarized in Table 30, which shows the number of days to death of 80 per cent of the termites, and the number of days to death of all twenty-five termites. A comparison of the data for either shows the relative toxicity of the preservatives tested.

The last column of the table comparing the amounts of paper eaten in each preservative test gives a rough idea of the repellence of each treatment. Termites killed with no apparent eating of the paper may have been poisoned from contact with the preservative, or they may have died from fumigation by the volatile materials in the preservative. However, only relatively permanent fumigants of low volatility would remain after the eight to ten weeks drying period. A slight eating of the paper with a short life period for the termites would indicate a highly toxic material. A slight eating of the paper with a relatively long life period of the termites indicates a highly distasteful or repellent product. Considerable eating of the paper with a long life period of the termites indicates a preservative of low repellence and low toxicity. All these tests were comparative. Some of the treated papers were not eaten by the termites as long as the waxed paper water pad was available. This necessitated the inclusion of a test of the waxed paper to prove that the insects in other tests had not been killed by it.

In the schedule of testing it was possible to allow paper treated with *California Road Oil*, coal-tar creosote (grade 1), and *International Wood Preservative* to dry for only two weeks after treatment. The presence of the more highly volatile creosote oils in coal-tar creosote and *International Wood Preservative* probably explains the apparent increased effectiveness of these materials over other products containing coal-tar creosote. *California Road Oil* had practically no odor after two weeks drying and its effect was probably as a contact poison. Petroleum oil products are most often effective by contact with insects.

Cabot's Shingle Stain and other similar shingle stains which have been dried for six months show a very greatly decreased toxicity over that shown in tests where the materials were dried only eight or ten weeks. This is probably due to the evaporation of the light creosote oils used in the manufacture of shingle stains of this type.

Dry-wood termite toxicity tests.—The toxicity tests with the dry-wood termite were carried out with divided wooden dowels. The full procedure of this toxicity work is described under laboratory dowel tests in chapter 34.

The dowels for the toxicity tests of proprietary preservatives were prepared by soaking in the preservatives for four hours. This treatment of these small pieces of wood gives a more thorough preservative treatment than the soaking, dipping, spraying, or brush treatment recommended by the manufacturers of these products. Nevertheless, full penetration of the dowels with the preservatives was obtained only with the lighter and more fluid materials. In most cases the treatment could be considered as principally a surface protection, with a penetration of 1/16 to 1/8 inch (0.16 to 0.30 cm.) from the surfaces in contact with the preservative. The treated dowels were allowed to air-dry for two or three months before being used in the toxicity tests. The dowels of coal-tar creosote, grade 1, and *International Wood Preservative* were again an exception to this, being allowed to dry for only two weeks. Consequently the results of these two tests are not strictly comparable with the others.

General conclusions.—These laboratory studies of proprietary preservatives are all comparative. Toxicity of the treated material, when eaten by the insects or when they came in contact with it, and its degree of repellence to termite attack, are important factors in preventing termite damage. Our laboratory tests reveal comparative indications of these factors, but it must be remembered that a material which shows poorly in these tests may have sufficient protective value to give good service in practical use. In use, a material which cannot be said to be termite-proof, but which is less desirable for termite food than abundant available untreated wood, will often give satisfactory service.

Permanence of the treatment is important from the standpoint of cost. Our laboratory tests did not deal with the permanence of proprietary preservatives. We have tried to cover this point by including available service records in our discussion of the preservatives.

CHAPTER 36

TESTS OF WOOD PRESERVATIVES TO PREVENT TERMITE ATTACK, CONDUCTED BY THE BUREAU OF ENTOMOLOGY, U. S. DEPARTMENT OF AGRICULTURE

BY

THOMAS E. SNYDER and JAMES ZETEK

TESTS AT FALLS CHURCH, VIRGINIA

Tests of chemical wood preservatives, superficial and impregnation treatments, and woods naturally resistant to termites have been conducted in the United States by the Bureau of Entomology in cooperation with the Forest Products Laboratory since 1911, when ground or "graveyard" tests were instituted at Falls Church, Virginia. The soil of this region is rather heavily infested with several species of *Reticulitermes,* since woodland is near by and infested wooden fences surround the test area. The pieces of treated test wood were sap southern yellow pine, 2 inches × 4 inches (5 cm. × 10 cm.) and 3 feet (90 cm.) in length. One-half of the wood was placed lengthwise in the ground and one-half remained above ground. The test pieces of naturally resistant woods were of larger but irregular dimensions. Untreated check stakes of sap southern yellow pine for comparison with the treated stakes were frequently replaced as they were destroyed by termites.

From time to time additional termites were artificially placed in the area by laying heavily infested logs on the ground and removing them during the winter, when the termites had left the wood and gone into the soil below the frost line. It was felt that some reliable data have been obtained from these rather small scale tests (Snyder, 1924*a*), but, due to the fact that there was practically no termite activity from October until March, it was believed that supplementary tests should be made where much quicker results could be obtained under severer conditions.

TESTS AT BARRO COLORADO ISLAND, CANAL ZONE, PANAMA

Consequently, in 1924, tests were begun on Barro Colorado Island in Gatun Lake, Canal Zone, Panama. At first these tests utilized merely 2 inch × 4 inch (5 cm. × 10 cm.) stakes similar to those tested at Falls Church, Virginia (fig. 119*b*). Later, impregnated sections of telegraph poles were added to the tests (fig. 119*a*) and, still later, small buildings, some as large as 19 feet × 19 feet × 10 feet high (5.8 m. × 5.8 m. × 3 m. high), constructed entirely of chemically

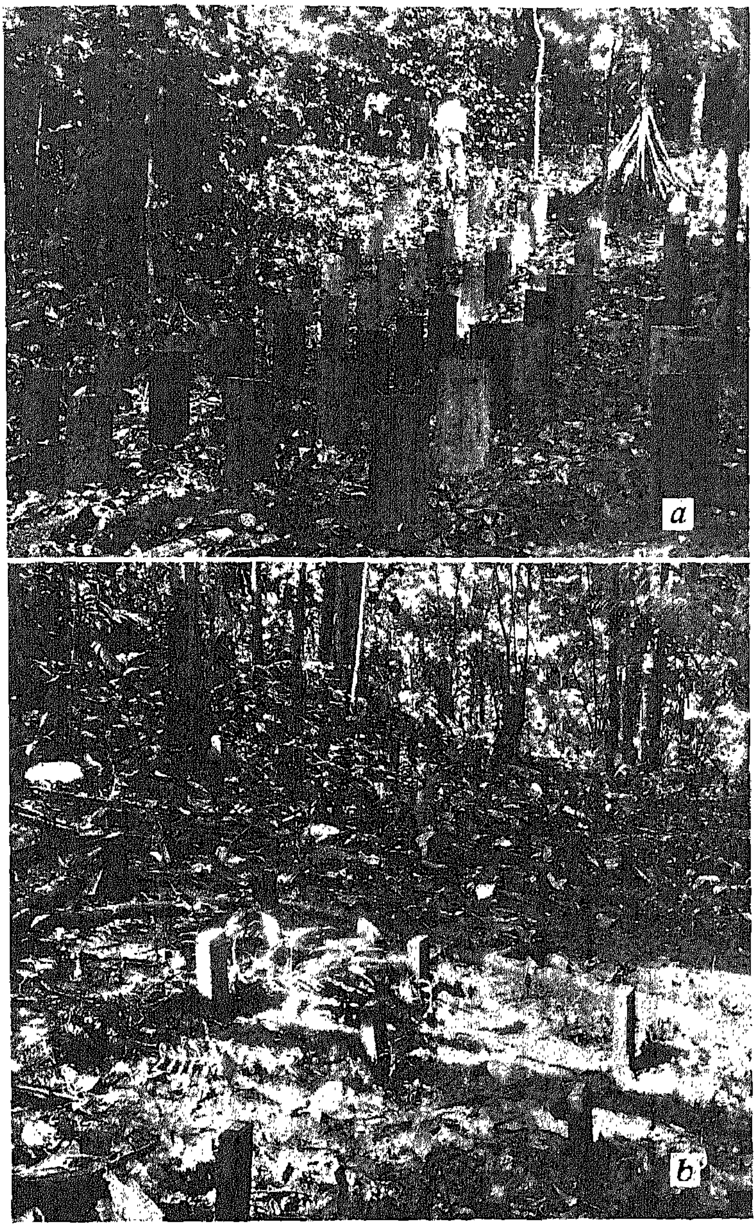

Fig. 119. Photographs of the test plots on Barro Colorado Island, Canal Zone, Panama. *a.* Portion of one of the plots where "graveyard tests" are being conducted, showing not only sections of telegraph poles but also 2-inch × 4-inch stakes. Note metal tags on each block of wood. *b.* Impregnated 2-inch × 4-inch stakes in one of the plots.

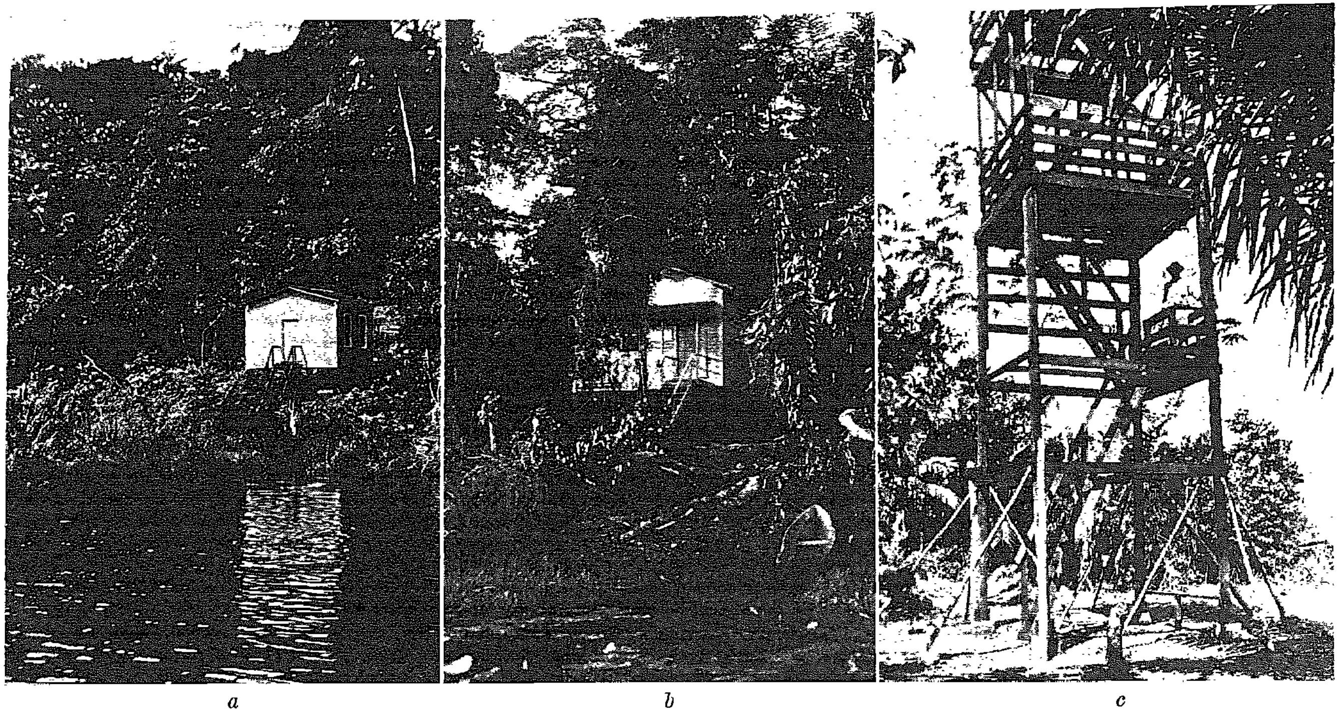

Fig. 120. Test structures erected on Barro Colorado Island. *a*. Demonstration termite-proof building erected in 1926. All timber used in this building was impregnated with either coal-tar creosote or zinc chloride, depending on where it was to be used. Interior woodwork, wallboard, and furniture were also suitably impregnated or poisoned. No attack by termites has occurred to the woodwork of this building (1932). *b*. Building of heart redwood from the Pacific Coast, constructed in 1927. Redwood supports were placed on concrete blocks. No marked penetration by termites has occurred (1932), although in a few places preliminary borings have been made. *c*. Watch tower erected on Barro Colorado Island in 1927, constructed entirely of heart redwood. The redwood pillars rest on concrete blocks. No marked penetration by termites has occurred (1932).

impregnated timbers (fig. 120*a*), were erected at various localities on the Island as additional tests. Observation towers, bridges, and other structures which would serve the same purpose were also constructed of impregnated timbers or of naturally termite-resistant woods (fig. 120*c*). In addition, tests of stakes of termite-resistant woods were also conducted.

Such graveyard tests in connection with service tests of treated telephone poles of the American Telephone and Telegraph Company, test poles, fence posts of our American railroads, test railroad ties in certain sections of railroads, and service tests of treated mine props and treated timbers in buildings, together with general field observations, indicate the best methods of impregnation and the most effective and suitable chemical preservatives, and give reliable relative data on termite-resistant woods.

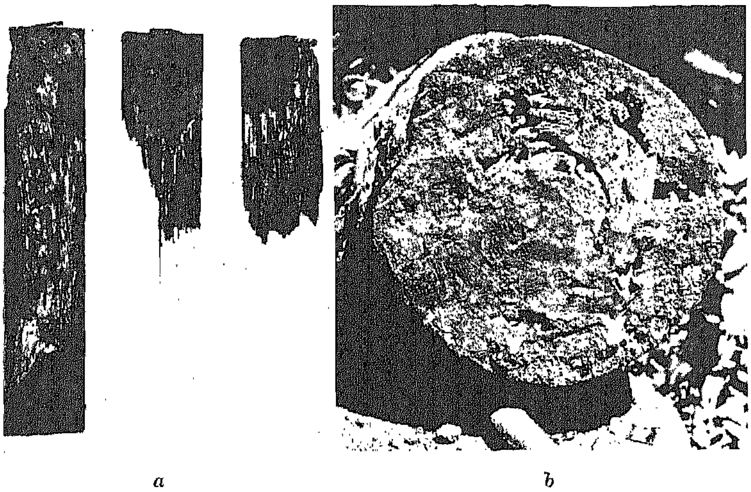

Fig. 121. Samples of damage by termites to test pieces in the test plot on Barro Colorado Island. *a.* Impregnated stakes nearly destroyed by subterranean termites. These tests were closed, due to the marked failure of this treatment after a test of one year and eight months. *b.* Untreated control honeycombed by subterranean termites after less than one year's exposure.

Accelerated tests, such as those made in a laboratory, are not conducted under such severe conditions, since other wood-boring insects, fungi, weathering, soil bacteria, chemicals in solution in the soil, etc., are either not present, or do not react as severely as in graveyard tests. It was believed, however, that graveyard tests should be conducted over a rather large area and that they should be split up, for obvious reasons, into many small plots rather than all be placed in one large plot. On Barro Colorado Island several widely separated plots are under observation, and the test buildings, towers, bridges, etc., are all on different plots. Thirty species of termites occur on Barro Colorado Island, where rain-forest conditions prevail. Of these thirty species, species of *Heterotermes, Coptotermes, Nasutitermes, Amitermes, Cylindrotermes,* and *Microcerotermes* have attacked the test woods in the plots (fig. 121*a–b*). No

TABLE 32

SUMMARY OF PRELIMINARY RESULTS OF TESTS OF WOOD PRESERVATIVES ON BARRO COLORADO ISLAND, CANAL ZONE, PANAMA, 1924–1932

A. TESTS ON TIMBER

Chemical	Method of treatment	Length test in ground	Results
Paraffin 40c (12) Ar 30-955	Impregnation	7 years, 8 months	Attacked by termites (paraffin sweats out) (test closed)
Chlorinated naphthalene	Boiling	7 years, 11 months	Attacked by termites[1]
Mercurizing solution	Impregnation (open tank)	7 years, 11 months	Attacked by termites
International Wood Preservative (Creosote?)	24-hour immersion	7 years, 11 months	Attacked by termites
Tanalith	Impregnation (pressure)	6 years, 8 months	Attacked[1] (test closed)
Selenine	Impregnation	2 years	Attacked (test closed)
Sodium fluoride	Impregnation (pressure)	5 years, 8 months	Attacked[1] (test closed)
Sprayed metal	Compressed air, spraying, electric arc	6 years, 8 months	Attacked (metal chipped off, and oxidized) (test closed)
Eastman No-D-K Wood Creosote	Brushing	6 years, 2 months	Attacked (test closed)
Concentrated lye	Soaking	1 year	Attacked (wood digested) (test closed)
Sulphur	?	3 years	Attacked (test closed)
Terralite	Brushing ?	2 years	Attacked (test closed)
Ac-Zol	Impregnation	5 years, 8 months	Attacked (slightly)
Sulphur and arsenic	Impregnation	6 years, 8 months	Attacked
Cedar oil	Impregnation	3 years, 5 months	Attacked (test closed)
Cedar oil and paraffin	Impregnation	5 years, 11 months	Attacked
Arsenics (Chemical Warfare Service)	Impregnation	5 years, 11 months	Slight attack on few test blocks
Montan wax and creosote	Impregnation	5 years, 9 months	Attacked (slightly)
Black asphalt varnish paint	Brushing	1 year	Attacked (test closed)
Red lead paint	Brushing	4 years, 3 months	Attacked (test closed)
Red copper paint	Brushing	5 years, 5 months	Attacked
Somosized treatment	Impregnation (open tank)	1 year	Attacked (test closed)
Arsenic and creosote	Impregnation	3 years, 1 month	No attack
Liquid coal-tar paint	Brushing	5 years, 1 month	Attacked
Heppell's Timber Fluid	Brushing	1 year, 6 months	Attacked (test closed)
Everlasting Paint	Brushing	5 years, 3 months	Attacked
Timbrol	Brushing	2 years, 7 months	Attacked (test closed)
Plybest	Coating	1 year	Attacked and loosened (test closed)
Lignophol	Impregnation	4 months	Attacked (test closed)
Avenarius Carbolineum	Brushing	2 years, 8 months	Attacked
Panamol	Brushing	1 year, 6 months	Attacked (test closed)
McEverlast	Impregnation	4 years, 7 months	Attacked
Barium carbonate 5%	Impregnation	3 years, 9 months	Attacked
Ammonia arsenite 2%	Impregnation	3 years, 9 months	No attack
Zinc chloride 5%	Impregnation	3 years, 9 months	No attack
Zinc-Meta-Arsenite 2.3-3.2%	Impregnation	3 years, 9 months	No attack
Coal-tar creosote	Impregnation	3 years, 9 months	No attack
5% Tar oil and petroleum	Impregnation	3 years, 9 months	No attack.
Barium arsenite petroleum emulsion, 5% oil and 50% aqueous solution	Impregnation	3 years, 9 months	No attack
Zinc arsenite petroleum emulsion, 50% oil and 50% aqueous solution	Impregnation	3 years, 9 months	No attack

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[1] Suitable treatment for timber not to be used in contact with the ground.

TABLE 32—*(Concluded)*

Chemical	Method of treatment	Length test in ground	Results
Cold treater dust	Placed in ground above wood	2 years	Attacked (test closed)
Paint and sand	Brushing	1 year, 7 months	Attacked (test closed)
Coal-tar creosote	Impregnation	7 years, 6 months	No attack
Coal-tar creosote	Impregnation	3 years, 8 months	No attack
Chlorinated naphthalene	Impregnation	4 years, 1 month	No attack
Borax	Impregnation	2 years	Attacked (test closed)
Nickel arsenate	Impregnation	3 years, 8 months	No attack
Thallium sulphate	Impregnation	3 years, 8 months	Attacked
Sodium bichromate	Impregnation	3 years, 8 months	Attacked
Sodium fluoride	Impregnation	2 years	Attacked (test closed)
Zinc-Meta-Arsenite	Impregnation	3 years, 8 months	No attack
Zinc chloride	Impregnation	2 years	Attacked (test closed)
Sodium fluosilicate	Impregnation	3 years, 8 months	Attacked
Nickel bichromate	Impregnation	3 years, 8 months	Attacked
Dinitrophenol	Impregnation	3 years, 8 months	Attacked
Tanalith	Impregnation	3 years, 8 months	Attacked
Triolith	Impregnation	2 years	Attacked and decayed (test closed)
White arsenic	Impregnation	3 years, 8 months	No attack
Chlorinated naphthalene	Impregnation	3 years, 8 months	No attack
Cold treater dust	Placed around wood	3 years, 8 months	No attack
Crewood	Impregnation	4 years, 1 month	Attacked
Flaimpruf	?	1 year, 8 months	Attacked (test closed)
* * * * * * * * * * *	* * * * * * *	* * * * * *	* * * * * * * * *
Zinc chloride	Impregnation	6 years	No attack
Chlorinated naphthalene	Impregnation	6 years	No attack
Coal-tar creosote	Impregnation (empty-cell)	6 years	No attack

B. Tests on Celotex with Surface Application of Chemical

Chemical	Length test in ground[2]	Results
Chlorinated naphthalene 2.8%	2 years	No attack
Minolith	2 years	Attacked (test closed)
Sodium fluoride 0.8%	2 years	Attacked (test closed)
Chlorinated naphthalene 1.4%	2 years	Attacked (test closed)
Copper sulfate 0.8%	2 years	Attacked (test closed)
Chlorinated naphthalene 0.7%	2 years	Attacked (test closed)
Sodium chloride 0.8%	2 years	Attacked (test closed)
Triolith 0.8%	2 years	Attacked (test closed)
Hexachlorobenzol 2.8%	2 years	Attacked (test closed)
Pickering solution	2 years	Attacked (test closed)
Sodium dinitrophenolate	2 years	Attacked (test closed)

[2] All tests to be repeated above ground where treatment will not be affected by leaching.

dry-wood termites, or Kalotermitidae, have been found attacking the test woods, and we have found it necessary to conduct different types of tests for the dry-wood termites. The most reliable of these tests we believe to be service tests of furniture and interior woodwork impregnated with chemical preservatives. In addition, sections of treated and untreated woods were placed between timbers infested with dry-wood termites, in an endeavor to obtain data on the most effective preservative to use.

Tests of poisons for wood-pulp products and other fiber or similar composition boards were made under severe test conditions in buildings already erected and in buildings erected for this special purpose. Another method which can be used to test these boards is to fasten a small section of treated board, about 12 or 24 inches (30 or 60 cm.) square, on a small, thin panel of untreated wood and place this, panel-side down, on the earth under a shed where there is protection from the weather. Of course, the soil is infested only with subterranean termites, but we feel that if the treatment will prevent attack by subterranean termites, it will also suffice against dry-wood termites.

On the other hand, preservatives or poisons which fail in ground tests might be effective for use above the ground where there is no leaching. No one test should be the basis for final conclusions on any preservative.

It is as yet too soon to make definite conclusions from the preliminary results obtained in these tests. Investigations over twenty years have demonstrated that pressure impregnations with coal-tar creosote alone are very effective. More recently, shorter tests have shown coal-tar creosote to be very effective in most combinations with other materials. Tests of wood impregnated with arsenical combinations have clearly shown after three years' test that arsenic is effective against termites, except, apparently, where not enough arsenic is used or where it is in a form easily leachable. Chlorinated naphthalene has also been effective in both the Panama and other tests. Several of the preservatives which failed in the ground tests did not fail when used above ground. Detailed statements with regard to the most promising poisons and preservatives will be published at a later date. Table 32 gives a summary of preliminary results.

Preliminary Results of International Exposure Tests
(Fourth Progress Report)

As a further supplement to these tests in Virginia and Panama, in 1928 an International Termite Exposure Test was instituted by the Forest Products Laboratory of the U. S. Forest Service and the U. S. Bureau of Entomology in cooperation with the governments of South Africa, Australia, Hawaii, and Panama. In addition to obtaining results under widely different environmental conditions, it is hoped to eliminate any possibility of personal bias. Unfortunately, the personal equation can never be entirely eliminated, since there will always be some differences of opinion as to just how to report on the severity of attack upon timbers. It is hoped eventually, however, to make all of the reports conform to certain standards.

Details of treatment, installation, and current inspections are given in the Proceedings of the American Wood-Preservers' Association for the years 1930, 1931, 1932, and 1933. Tables 33–37 show the results of the most recent inspections, through the fourth progress report.

The test specimens were of sap pine about 2 inches × 4 inches × 18 inches in size. Four sets of such specimens were treated at the Forest Products Laboratory in 1928, one set for each of the four countries just named. Through the cooperation of Government officers in each country the specimens were installed in soil known to contain termites and inspections are made and reported at regular intervals. In 1931 a set of over 500 similar specimens was treated with a different series of chemicals and installed on Barro Colorado Island. Cost limitations made it impractical to send duplicates of this set to the other stations.

The following tables show details as to the chemicals used, the absorptions, and the number of specimens at each exposure station and give the results of the inspections made at each station by the cooperating Government officers.

These tables must not be considered as showing conclusively the relative effectiveness of the different preservatives. Comparison of the results from the different stations shows marked differences. For example, the nickel arsenate specimens are still sound at Barro Colorado Island but in Australia all but one are either attacked or destroyed. On the other hand, the coal-tar creosote specimens are sound in Australia and South Africa but are being attacked at Honolulu and Barro Colorado Island. These differences undoubtedly result from differences in climatic and exposure conditions and species of termites at the different stations, differences in amount or distribution of preservative in individual specimens, differences in the inspection methods and classification used by the several inspectors, and perhaps other factors not yet recognized. The experiments should continue several years yet before conclusions are drawn. Use of these data for commercial promotion of any preservative is not warranted.

Two creosoted specimens at Barro Colorado Island and one at Honolulu are reported destroyed since the third progress report. Their absorptions were 2.1, 5.4, and 5.0 pounds per cubic foot, respectively. The two Zinc-Meta-Arsenite specimens destroyed at Barro Colorado Island had an absorption of 0.58 pound per cubic foot each, while the one destroyed at Honolulu had an absorption of 0.68 pound per cubic foot. The Halowax specimen destroyed by rot at Barro Colorado Island had an absorption of 20.6 pounds per cubic foot, and that destroyed by termites at Honolulu had absorbed 11.6 pounds per cubic foot. As the experiment grows older and a larger percentage of the more effective preservatives has failed it may be possible to show a definite relationship between the absorption and the life of the specimens in each preservative group. The depth and uniformity of penetration will, of course, have a very important influence, for even with the best preservatives and good absorptions both termites and decay will sooner or later locate and destroy the places that have not been penetrated satisfactorily. Many of the specimens removed from test are being returned to Madison so that observations on penetration can be made when desired.

TABLE 33

CONDITION OF SPECIMENS (SET NO. 1) SUBJECTED TO TERMITE ATTACK AT BARRO COLORADO ISLAND, C. Z., PANAMA, AFTER ABOUT 50 MONTHS' SERVICE. SPECIMENS PLACED IN SERVICE AUGUST 10, 1928

Summary based on data submitted by James Zetek, Bureau of Entomology, U. S. Department of Agriculture

Preservative	No. of specimens	Absorption			Condition of specimens October 1932						Found destroyed at each inspection							
		Minimum	Maximum	Average	Good		Attacked		Destroyed		Feb. 1929 (6 mos.)	Oct. 1929 (14 mos.)	April 1930 (20 mos.)	Sept. 1930 (25 mos.)	Mar. 1931 (31 mos.)	Oct. 1931 (38 mos.)	April 1932 (44 mos.)	Oct. 1932 (50 mos.)
		Pounds per cu. ft.			*No.*	%	*No.*	%	*No.*	%	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*
Coal-tar creosote	12	2.10	28.00	13.30	9	75.0	1[a]	8.3	2[b]	16.7	....	....	....	....	....	....	....	2
Halowax[1]	7	5.20	30.80	19.10	6	85.7	....	....	1[c]	14.3	....	....	....	....	....	....	....	1
Zinc-meta-arsenite	8	0.58	1.17	0.78	....	....	6[d]	75.0	2[b]	25.0	....	....	....	....	....	....	....	2
Zinc chloride	8	0.80	2.51	1.53	....	....	....	....	8[c]	100.0	....	1	3	4	....	....	....	....
Sodium fluoride	8	0.88	3.26	1.75	....	....	....	....	8[a]	100.0	1	5	2	....	....	....	....	....
Borax	8	1.03	2.92	1.85	....	....	....	....	8[a]	100.0	....	6	2	....	....	....	....	....
Nickel arsenate	8	0.73	1.79	1.28	8	100.0	....	....	....	....	....	....	....	....	....	....	....	....
Thallium sulphate	7	0.16	0.33	0.24	....	....	1[b]	14.3	7[e]	85.7	....	....	....	....	2	2	1	2
Sodium bichromate	8	0.68	3.15	1.75	....	....	4[a]	50.0	4[a]	50.0	1	....	....	1	1	....	....	1
Sodium fluosilicate	8	0.35	1.02	0.67	....	....	1[b]	12.5	7[f]	87.5	....	1	1	....	1	....	....	4
Nickel bichromate	8	0.88	2.50	1.53	....	....	6[a]	75.0	2[a]	25.0	2	....	....	....	....	....	....	....
Dinitrophenol	8	0.18	0.44	0.30	....	....	1[b]	12.5	7[g]	87.5	....	....	....	5	1	1	....	....
Tanalith[2]	8	0.35	1.15	0.70	....	....	1[b]	12.5	7[e]	87.5	....	....	2	2	....	....	1	2
Triolith[3]	8	0.31	1.17	0.68	....	....	....	....	8[h]	100.0	2	4	2	....	....	....	....	....
White arsenic	8	0.70	1.08	0.84	....	....	4[j]	50.0	4[k]	50.0	....	....	....	....	....	....	2	2
Anaconda Wood Preservative[4]	4	....	....	....	1	25.0	2[c]	50.0	1[a]	25.0	....	....	....	....	....	....	....	1
Untreated controls	4	....	....	....	....	....	....	....	4[a]	100.0	3	1	....	....	....	....	....	....

[1] Chlorinated naphthalene.

[2] A fluoride-phenol-arsenic mixture.

[3] A fluoride-phenol mixture.

[4] Cold treater dust, chiefly crude arsenic.

[a] By termites only.

[b] By both termites and decay.

[c] By decay only.

[d] Four specimens contain decay only.

[e] Four by termites only.

[f] Two specimens by termites only.

[g] Five by termites only.

[h] Seven by termites only.

[j] Two contain decay only.

[k] Mostly by decay.

TABLE 34

CONDITION OF SPECIMENS (SET NO. 2) SUBJECTED TO TERMITE ATTACK AT CANBERRA, AUSTRALIA, AFTER ABOUT THREE YEARS' SERVICE.[1]

SPECIMENS PLACED IN SERVICE MAY 31 TO JULY 18, 1929

Summary based on data submitted by G. F. Hill and J. E. Cummins, Council for Scientific & Industrial Research, Commonwealth of Australia

Preservative	Number of specimens	Absorption			Number of specimens not in contact with termites[2]	Condition of specimens—August 1932						Found destroyed at each inspection		
		Minimum	Maximum	Average		Good		Attacked by termites		Destroyed by termites		July 1930 (1 year)	July 1931 (2 years)	Aug. 1932 (3 years)
		Pounds per cubic foot				Number	Per cent	Number	Per cent	Number	Per cent	Number	Number	Number
Coal-tar creosote	12	2.4	26.6	13.1	11	12	100.0	....	....	....	....	....	....	....
Halowax	7	8.3	33.7	19.8	6	7	100.0	....	....	....	....	....	....	....
Zinc-meta-arsenite	8	0.57	1.20	0.76	7	8[a]	100.0	....	....	....	....	....	....	....
Zinc chloride	8	0.99	2.34	1.52	1	....	....	4[b]	50.0	4[a]	50.0	....	2	2
Sodium fluoride	8	0.89	2.65	1.66	0	....	....	3[b]	37.5	5	62.5	....	2	3
Borax	8	1.15	2.70	1.84	1	1	12.5	3	37.5	4	50.0	....	2	2
Nickel arsenate	8	0.85	1.76	1.29	1	1	12.5	4	50.0	3	37.5	1	1	1
Thallium sulphate	7	0.17	0.34	0.24	2	1	14.3	3	42.9	3	42.8	....	2	1
Sodium bichromate	8	0.69	3.01	1.75	0	....	....	....	....	8	100.0	3	5	....
Sodium fluosilicate	8	0.35	0.89	0.65	2	3[a]	37.5	5[b]	62.5	....	....	....	....	....
Nickel bichromate	8	0.91	2.39	1.58	0	....	....	....	....	8	100.0	8	....	....
Dinitrophenol	8	0.19	0.44	0.30	2	5[a]	62.5	3[b]	37.5	....	....	....	....	....
Tanalith	8	0.40	1.10	0.71	3	6[a]	75.0	2	25.0	....	....	....	....	....
Triolith	8	0.42	1.09	0.69	0	2	25.0	6	75.0	....	....	....	....	....
White arsenic	8	0.78	1.21	0.90	6	7	87.5	1	12.5	....	....	....	....	....
Anaconda Wood Preservative[3]	2	....	....	....	....	....	....	....	....	....	....	....	....	....
Untreated controls	6	....	....	....	0	....	....	1[b]	16.7	5	83.3	2	2	1

[1] About one-half of the specimens of most groups were tested against *Eutermes exitiosus* and the other half against *Coptotermes lacteus*.

[2] Includes specimens in service at the time of the August 1932 inspection that were not in contact, either wholly or in part, with the termites.

[3] Not tested after first year—found to be in good condition after about one year's service.

[a] One specimen slightly affected by decay.

[b] One specimen contains both decay and termites.

TABLE 35

CONDITION OF SPECIMENS (SET NO. 3) SUBJECTED TO TERMITE ATTACK AT HONOLULU, TERRITORY OF HAWAII, AFTER ABOUT 36 MONTHS' SERVICE.
SPECIMENS PLACED IN SERVICE APRIL 27, 1929

Summary based on data submitted by D. T. Fullaway, Entomologist, Board of Commissioners of Agriculture and Forestry, Honolulu, T. H.

Preservative	No. of specimens	Absorption			Condition of specimens April, 1932						Found destroyed at each inspection		
		Minimum	Maximum	Average	Good		Attacked[1]		Destroyed[1]		April 1930 (1 year)	April 1931 (2 years)	April 1932 (3 years)
		Pounds per cubic foot			*Number*	*Per cent*	*Number*	*Per cent*	*Number*	*Per cent*	*Number*	*Number*	*Number*
Coaltar creosote	12	3.20	25.20	13.2	7	58.3	3	25.0	2	16.7	....	1	1
Halowax	7	10.00	40.20	20.7	6	85.7	....	....	1	14.3	....	....	1
Zinc-meta-arsenite	8	0.57	1.20	0.78	3	37.5	4	50.0	1	12.5	....	....	1
Zinc chloride	8	1.02	2.25	1.51	....	....	3	37.5	5	62.5	....	3	2
Sodium fluoride	8	1.03	2.46	1.67	....	....	....	....	8	100.0	....	8	....
Borax	8	1.20	2.66	1.87	....	....	....	....	8	100.0	....	6	2
Nickel arsenate	8	0.92	1.72	1.30	4	50.0	4	50.0	....	....	....	....	....
Thallium sulphate	7	0.17	0.36	0.24	....	....	....	....	7	100.0	....	3	4
Sodium bichromate	8	0.74	2.98	1.77	....	....	....	....	8	100.0	1	5	2
Sodium fluosilicate	8	0.36	0.88	0.64	....	....	7	87.5	1	12.5	....	....	1
Nickel bichromate	8	0.97	2.35	1.60	4	50.0	3	37.5	1	12.5	....	....	1
Dinitrophenol	8	0.19	0.43	0.30	....	....	3	37.5	5	62.5	....	3	2
Tanalith	8	0.47	1.09	0.72	....	....	2	25.0	6	75.0	....	1	5
Triolith	8	0.44	1.06	0.70	....	....	....	....	8	100.0	....	6	2
White arsenic[2]	8	0.78	1.16	0.97	1	12.5	1	12.5	6	75.0	....	....	6
Anaconda Wood Preservative[3]	4	....	....	....	4	100.0	....	....	....	....	....	....	....
Untreated controls	4	....	....	....	....	....	....	....	4	100.0	1	3	....

[1] Both decay and termites at work. A few specimens removed for decay only but mostly for termite attack or combined attack by termites and decay.

[2] Arsenious acid powdered.

[3] Cold treater dust—exposed one year only.

TABLE 36

CONDITION OF SPECIMENS (SET NO. 4) SUBJECTED TO TERMITE ATTACK AT PIENAAR'S RIVER EXPERIMENT STATION, TRANSVAAL, SOUTH AFRICA, AFTER ABOUT 44 MONTHS' SERVICE. SPECIMENS PLACED IN SERVICE OCTOBER 2, 1928

Summary based on data submitted by Nils B. Eckbo, Forest Department, Union of South Africa

Preservative	No. of specimens	Absorption			Condition of specimens June 8, 1932						Found destroyed at each inspection					
		Minimum	Maximum	Average	Good		Attacked by termites		Destroyed by termites[a]		June 1929 (8 mos.)	Nov. 1929 (14mos.)	Sept. 1930 (23mos.)	May 1931 (31mos.)	Dec. 1931 (38mos.)	June 1932 (44mos.)
		Pounds per cubic foot			*No.*	*Per cent*	*No.*	*Per cent*	*No.*	*Per cent*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*
Coal-tar creosote	11[b]	4.30	24.50	13.30	11	100.0	....	....	....	....	....	....	....	....	....	....
Halowax	6[b]	11.40	42.10	21.10	6	100.0	....	....	....	....	....	....	....	....	....	....
Zinc-meta-arsenite	7[b]	0.54	1.23	0.77	7	100.0	....	....	....	....	....	....	....	....	....	....
Zinc chloride	8	1.02	2.24	1.53	....	....	....	....	8	100.0	3	5	....	....	....	....
Sodium fluoride	7[b]	1.05	2.39	1.67	....	....	....	....	7	100.0	....	....	3	4	....	....
Borax	8	1.25	2.51	1.84	....	....	....	....	8	100.0	1	3	4	....	....	....
Nickel arsenate	8	0.95	1.66	1.29	3	37.5	5	62.5	....	....	....	....	....	....	....	....
Thallium sulphate	7	0.18	0.38	0.24	....	....	....	....	7	100.0	....	....	7	....	....	....
Sodium bichromate	8	0.79	2.91	1.77	....	....	4	50.0	4	50.0	2	2	....	....	....	....
Sodium fluosilicate	7[b]	0.37	0.88	0.64	....	....	....	....	7	100.0	....	....	1	3	3	....
Nickel bichromate	7[b]	0.99	2.30	1.59	....	....	....	....	7	100.0	1	....	....	5	1	....
Dinitrophenol	7[b]	0.19	0.42	0.30	....	....	7	100.0	....	....	....	....	....	....	....	....
Tanalith	7[b]	0.48	1.02	0.73	....	....	5	71.4	2	28.6	....	....	....	....	2	....
Triolith	7[b]	0.45	1.05	0.70	....	....	4	57.2	3	42.8	....	....	....	3	....	....
White arsenic[c]	8	0.76	1.17	0.90	8	100.0	....	....	....	....	....	....	....	....	....	....
Anaconda Wood Preservative[d]	2[e]	....	....	....	2	100.0	....	....	....	....	....	....	....	....	....	....
Untreated controls	4	....	....	....	....	....	....	....	4	100.0	1	1	1	1	....	....

---

[a] When 50 per cent or less of a specimen remained it was classed as destroyed.

[b] One specimen pilfered, therefore eliminated from the experiment and the number of specimens in test reduced accordingly.

[c] Arsenious acid, powdered.

[d] Cold treater dust.

[e] Two specimens pilfered, therefore eliminated.

TABLE 37

CONDITION OF SPECIMENS (1931 SERIES) SUBJECTED TO TERMITE ATTACK AT BARRO COLORADO ISLAND, C. Z., PANAMA, AFTER ABOUT 14 MONTHS' SERVICE. SPECIMENS PLACED IN SERVICE AUGUST 1931

Summary based on data submitted by James Zetek, Bureau of Entomology, U. S. Department of Agriculture

Preservative	No. of specimens	Absorption of preservative				Condition of specimens October, 1932					
			Minimum	Maximum	Average	Good		Attacked by termites		Destroyed by termites	
			Pounds per cubic foot			*Number*	*Per cent*	*Number*	*Per cent*	*Number*	*Per cent*
Coal tar creosote (Grade 1—A. W. P. A. specifications)	8	Oil	5.2	8.7	7.0	8	100.0	....	....	....	....
Coal tar creosote (Grade 1—A. W. P. A. specifications)	8	Oil	11.5	14.9	13.6	8	100.0	....	....	....	....
10% coal tar creosote—90% petroleum (by volume)	8	Mixture	4.7	10.0	6.5	8	100.0	....	....	....	....
10% coal tar creosote—90% petroleum (by volume)	8	Mixture	12.7	16.8	14.2	8	100.0	....	....	....	....
25% coal tar creosote—75% petroleum (by volume)	8	Mixture	5.0	98.	7.0	8	100.0	....	....	....	....
25% coal tar creosote—75% petroleum (by volume)	8	Mixture	12.6	16.0	14.0	8	100.0	....	....	....	....
50% coal tar creosote—50% petroleum (by volume)	8	Mixture	5 4	8.5	7.1	8	100 0	....	....	....	....
50% coal tar creosote—50% petroleum (by volume)	8	Mixture	10.4	17.3	14.5	8	100 0	....	....	....	....
75% coal tar creosote—25% petroleum (by volume)	8	Mixture	6.1	8.5	7.2	8	100 0	....	....	....	....
75% coal tar creosote—25% petroleum (by volume)	8	Mixture	10 1	19 3	14.8	8	100 0	....	....	....	....
Petroleum	8	Oil	5.5	9.8	7.0	8	100.0	....	....	....	....
Petroleum	8	Oil	12.3	16.8	14 4	8	100.0	....	....	....	....
Shale oil (crude)	8	Oil	5.2	8.5	6.7	5	62.5	2	25.0	1	12.5
Shale oil (crude)	8	Oil	11 6	16.3	13.9	8	100.0	....	....	....	....
Shale oil (distillate)	8	Oil	5.5	8 7	6.9	7	87 5	1	12 5	....	....
Shale oil (distillate)	8	Oil	11.8	20.3	13.9	7	87.5	1	12.5	....	....
Water gas tar	8	Oil	5.5	9.3	7 2	8	100.0	....	....	....	....
Water gas tar	8	Oil	11.4	17.8	14.6	8	100.0	....	....	....	....
Cannel coal oil	8	Oil	6.2	7.8	7.0	8	100 0	....	....	....	....
Cannel coal oil	8	Oil	10.9	16 1	13 4	8	100.0	....	....	....	....
1.3% beta naphthol—98.7% alcohol (by weight)	8	$C_{10}H_7OH$	.31	.44	.36	....	....	5[a]	62.5	3	37.5
2.6% beta naphthol—97.4% alcohol (by weight)	8	$C_{10}H_7OH$	.52	.79	.69	....	....	6	75.0	2	25.0
3% beta naphthol—10% pine oil—87% petroleum (by weight)	8	Solution	4.8	9.2	6 8	8	100.0	....	....	....	....
3% beta naphthol—10% pine oil—87% petroleum (by weight)	8	Solution	9.5	23.7	15.8	8	100.0	....	....	....	....
Bruce preservative No. 5A [1]	8	Oil	7.0	9.2	8 0	8	100.0	....	....	....	....
Bruce preservative No. 5A [1]	8	Oil	11.4	19.5	14.8	8	100.0	....	....	....	....
Pine oil	8	Oil	5.8	9.0	7.5	....	....	3	37.5	5	62.5
Pine oil	8	Oil	11.5	21.6	14.3	....	....	5	62.5	3	37.5
Spirittine chemically treated pine oil	8	Oil	6.4	7.5	6.9	8	100.0	....	....	....	....
Spirittine chemically treated pine oil	8	Oil	11.0	19.1	13.9	8	100.0	....	....	....	....

Spirittine wood preservative[2]	8	Oil	5.5	9 3	7.0	8	100.0	......	......	......	......
Spirittine wood preservative[2]	8	Oil	10.6	20.0	13.8	8	100.0	......	......	......	......
Termite oil No. 1[3]	8	Oil	6.2	8.7	7.3	1	12.5	5	62.5	2	25.0
Termite oil No. 1[3]	8	Oil	12.2	17.2	14.5	4	50.0	4	50.0	......	......
Termite oil No. 3[3]	8	Oil	4.5	6.0	5.3	3	37.5	4	50.0	1	12 5
Termite oil No. 3[3]	8	Oil	8.4	12.7	10.4	7	87.5	1	12.5	......	......
4.8% dinitrochlorobenzene—95.2% petroleum (by weight)	8	Solution	3.8	9.5	6.5	8	100.0	......	......	......	......
4.8% dinitrochlorobenzene—95.2% petroleum (by weight)	8	Solution	9.8	20.4	14 8	8	100.0	......	......	......	......
9.1% dinitrochlorobenzene—90.9% petroleum (by weight)	8	Solution	3.4	11.9	6.8	8	100.0	......	......	......	......
9.1% dinitrochlorobenzene—90.9% petroleum (by weight)	8	Solution	11.9	18.9	14.8	8	100.0	......	......	......	......
5% dinitronaphthalene—95% petroleum (by weight)	8	Solution	4.5	9.6	7.4	8	100.0	......	......	......	......
5% dinitronaphthalene—95% petroleum (by weight)	8	Solution	9.7	20.6	14.3	8	100.0	......	......	......	......
9.5 and 10% dinitronaphthalene—90.5 and 90% petroleum (by weight)	8	Solution	5.0	9.3	7.0	8	100.0	......	......	......	......
9.5 and 10% dinitronaphthalene—90.5 and 90% petroleum (by weight)	8	Solution	10.2	20.1	13.7	8	100.0	......	......	......	......
1.3% tetrachlorphenol—98.7% alcohol (by weight)	8	C_6HCl_4OH	.29	.44	.38	2	25.0	6[b]	75.0	......	......
2.6% tetrachlorphenol—97.4% alcohol (by weight)	8	C_6HCl_4OH	.70	.79	.75	6	75.0	2	25.0	......	......
4.8 and 5% tetrachlorphenol—95.2 and 95% petroleum (by weight)	8	Solution	5.8	9.9	7.1	8	100.0	......	......	......	......
4.8 and 5% tetrachlorphenol—95.2 and 95% petroleum (by weight)	8	Solution	10.5	16.6	13.8	8	100.0	......	......	......	......
9.1% tetrachlorphenol—90.9% petroleum (by weigth)	8	Solution	4.6	10.7	7.3	8	100.0	......	......	......	......
9.1% tetrachlorphenol—90.9% petroleum (by weight)	8	Solution	10.8	19.0	14.1	8	100.0	......	......	......	......
4.9% carbazole—95.1% petroleum (by weight)	8	Solution	5.9	8.8	7.0	7	87.5	......	......	1	12.5
4.9% carbazole—95.1% petroleum (by weight)	8	Solution	11.6	18.3	14.3	7	87.5	1	12.5	......	......
9.2 and 10% carbazole—90.8 and 90% petroleum (by weight)	8	Solution	6.3	8.7	7.1	8	100.0	......	......	......	......
9.2 and 10% carbazole—90.8 and 90% petroleum (by weight)	8	Solution	11.4	17.3	13.5	8	100.0	......	......	......	......
6% Ac-Zol[4] solution (by volume)	8	Solution	23.6	32 8	28 0	8	100.0	......	......	......	......
10% Ac-Zol[4] solution (by volume)	8	Solution	26 9	36.4	30.9	8	100.0	......	......	......	......
5.1% Tanalith-*U*[5] (by weight)	8	Salt	1.40	1 58	1.45	8	100 0	......	......	......	......
No-D-K "B" (wood-tar creosote)	8	Oil	6.1	8.5	7.0	8	100.0	......	......	......	......
No-D-K "B" (wood-tar creosote)	8	Oil	12.4	18.9	14.0	6	75.0	2	25.0	......	......
5.6% sodium arsenite solution (by weight)	8	Na_2HAsO_3	1.28	1.62	1 47	8	100 0	......	......	......	......
4.6% arsenic trioxide solution (by weight)	8	As_2O_3	.84	1.56	1 33	8	100.0	......	......	......	......
4.8 and 7.4% barium hydroxide solution (by weight)	8	$Ba(OH)_2$	1.34	1 99	1.58	......	......	3	37 5	5	62 5
2% sodium silicofluoride solution (by weight)	8	Na_2SiF_6	.36	.58	.49	......	......	5	62.5	3	37.5
16.8% mono ammonium phosphate solution (by weight)	8	$NH_4H_2PO_4$	4.0	6 2	5.0	......	......	......	......	8	100 0
Celcure process[6] (steamed 1 hour after treatment)	8	Solution	26.5	31 0	29.5	8	100.0	......	......	......	......
Celcure process[7] (steamed 1 hour after treatment)	8	Solution	21 0	33.0	28.3	8	100.0	......	......	......	......
Celcure process[6]	8	Solution	24 1	31 4	28.3	7	87.5	1	12.5	......	......
Celcure process[7]	8	Solution	25.8	31.0	29.1	8	100.0	......	......	......	......

[1] 5 per cent beta naphthol in an oil mixture.
[2] Pine tar derivative.
[3] Pine oil derivative.
[4] Copper-zinc-phenol mixture.
[5] Fluoride-phenol mixture.
[6] 2.8% copper sulphate (crystals) 2.8% potassium dichromate.
1.3% pyroligneous acid solution (by weight).
[7] 5.6% copper sulphate (crystals).
5.6% potassium dichromate.
2.7% pyroligneous acid (by weight).
[a] One specimen shows decay.
[b] Two specimens show decay.

CHAPTER 37

PAINTS AND TERMITE DAMAGE

BY

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The use of paint for protecting wood from termite damage has often been proposed. The necessity of investigating the value of paint in termite control work was brought to the attention of the Committee by two factors. Many of the termite remedies found on the market in the early part of the Committee's work were paints containing poisonous material. During the first eighteen months of the investigation no conclusive instances were found in the field where wood attacked by termites had been infested through a painted surface. Wood was found which had been attacked where there were cracks due to imperfect framing of the lumber and where the paint did not cover the wood surfaces in the joints and in weather checks, cracks, and holes in exposed timber. Plane exposed wood surfaces were seldom found to be attacked by termites. Paint is commonly used for the protection of exposed wood surfaces, so it was impossible to tell from field observations whether the freedom of smooth surfaces from termite attack was aided by or due to the paint, or whether it was due only to mechanical difficulties of infestation.

A number of paints have been tested in South Africa to determine their values in preventing termite damage. Test stakes were painted and set in the soil for exposure to attack by subterranean termites. The paints showed some resistance to termite attack, adding about a year to the life of the stakes. But this type of test is not suited for testing the value of paint. Paint is not made for use in contact with damp soil. Moisture is absorbed by the wood through the paint film; this expands the wood fibres, cracks the paint surface, and causes the paint to flake off. When the paint film is broken its protective value is lost.

If paint has value for preventing termite damage it should demonstrate this by preventing infestation by the dry-wood termite in wood used above ground. Methods of construction recommended for the Orient, where dry-wood termites must be considered, include a thorough painting of the structure to decrease the chances of infestation. The work of the Committee confirms this recommendation, since it shows that well painted wood is less liable to infestation by the dry-wood termite.

TESTS

The systematic study of the value of paint in termite control was carried out by the Committee in three series of tests: (1) A laboratory test of the toxicity to termites of various paints and paint constituents was made on a comparative basis. (2) Laboratory tests were made of the penetration of various paint films by the winged form of the dry-wood termite. (3) The last test was on a semi-field scale to study the possibility of infestation of painted wood by the dry-wood termite.

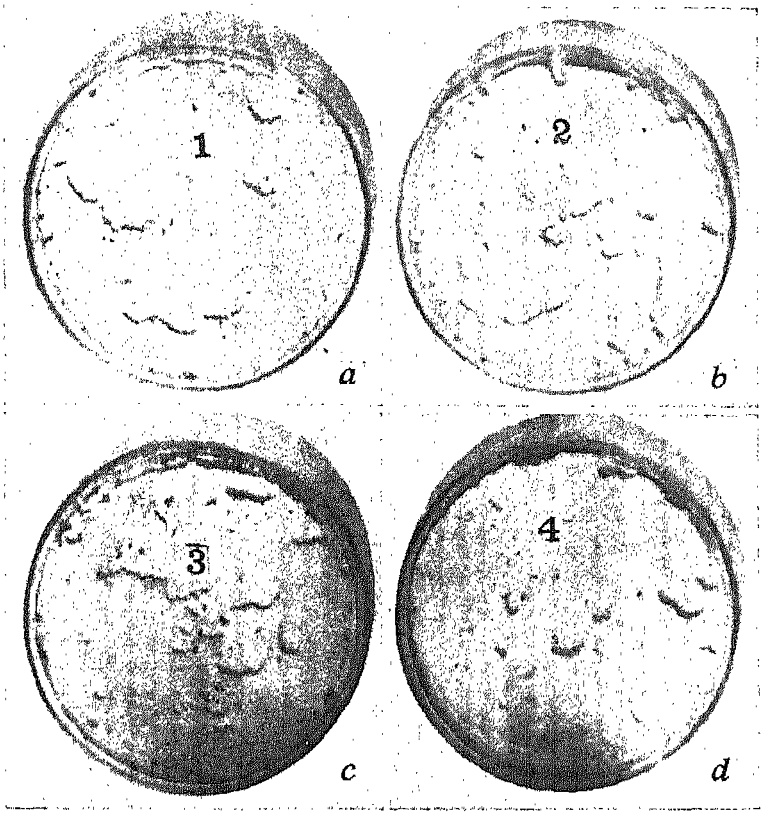

Fig. 122. Unpainted paper controls in test to determine the toxicity of paints to termites; amounts of papers eaten by ten nymphs of the damp-wood termite, *Zootermopsis angusticollis*, in 111 days. Number of termites alive at end of period: *a*, 8; *b*, 10; *c*, 10; *d*, 5.

Toxicity of paints to termites; method of testing.—This test of the toxicity of paint to termites included forty-seven paints. Fifteen of these were chosen as typical paints for general purposes, another twenty-five were recommended and submitted by manufacturers as having constituents which might add to their resistance to termite attack, and seven were asphaltic paints of varying hardness. Three thorough brush coats of paint were applied to each side of filter paper 12 cm. in diameter. The painting was done by an experienced painter so that the paint films would be comparable with those used in practice. The painted papers were allowed to dry for six months before they were used in the toxicity tests. This precluded any possible effect of fumigation by the volatile materials used in the paint vehicle.

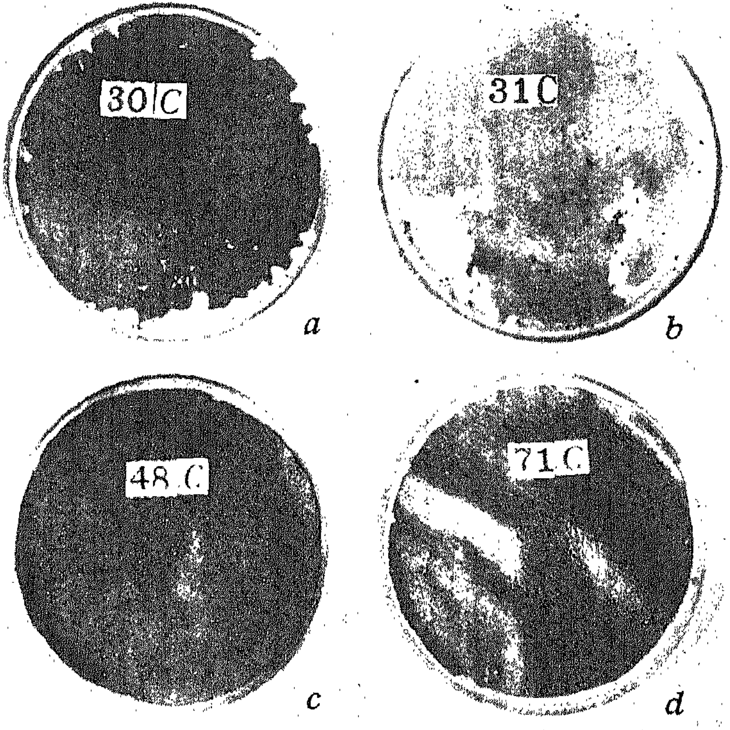

Fig. 123. Painted papers in test to determine the toxicity of paints to termites; amounts of papers eaten by ten nymphs of the damp-wood termite, *Zootermopsis angusticollis.* Eighty per cent of termites dead at end of (a) 54 days; (b) 125 days; (c) 28 days; (d) 30 days. *a.* Gilsonite vehicle metal paint. Pigment 35 per cent, vehicle 65 per cent; pigment 50 per cent ferric oxide, 50 per cent silica; vehicle 15 per cent heat-treated linseed oil, 15 per cent heat-treated China wood oil, 20 per cent Gilsonite, 50 per cent substitute turpentine. *b.* High-grade spar varnish. Vehicle 100 per cent; 39 per cent heat-treated China wood oil, 13 per cent ester gum, 48 per cent substitute turpentine. *c.* Vehicle 100 per cent asphalt, carbon bisulphide. *d.* Green crossarm paint. Pigment: chromic oxide, ½ per cent white arsenic. Vehicle: 100 per cent raw linseed oil and drier.

Each paper perfectly coated with one paint was cut and fitted into a 9 cm. Petri dish (figs. 122, 123). Ten full-grown nymphs of the damp-wood termite, *Zootermopsis angusticollis,* were used in each test. A few drops of water were kept on each paper throughout the test as a moisture supply for the termites. Four control groups were also run in which the termites were placed on unpainted filter paper. Here the drops of water were kept on small squares of waxed paper. Daily observations were made and the date of the first noticeable eating of the test paper recorded. Record was also kept of the number of termites still alive at each inspection. At the conclusion of the test a photograph of each test paper was taken to allow comparison of the amount of paper eaten in each test. The data from these observations are available in the records of the Committee but are not included in this report.

Observations.—One manufacturer making gilsonite paints, *i. e.*, paints of a hard mineral asphalt, sold paint containing 5 per cent sodium arsenite as a termite-proof material. This poisoned paint was tested with unpoisoned gilsonite paint and each showed about the same toxicity. The gilsonite seemed to coat the particles of poisonous sodium arsenite, making them inactive. Paints in general probably decrease the toxic power of poisons added to them. Nevertheless, it is evident from these toxicity tests that all paints do not completely destroy the effectiveness of added poisons.

The correlation between properties desirable in paints for preventing termite damage and the composition of the paints is not very satisfactory. Constituents of paint which have suitable properties are not strikingly pointed out. Nevertheless the series of paints tested show a wide range of toxic power, repellence, and distastefulness, as shown by the relative amounts of paper eaten. The full data from this test are available in the records of the Committee for those who wish to attempt some practical use of them. The results are of considerable importance, but they do not indicate complete protection from termite damage even by the more suitable paints.

This toxicity test is not practical. Termites in the field would not go along the surface of a board eating all the paint off of it. They drill one small hole through the paint and immediately enter the unprotected wood beneath it, or enter the wood through cracks or breaks in the paint film. In our toxicity test the termites were forced to eat the painted paper or starve. The amount of paint eaten by the insects under test was many times the amount necessary to eat through a paint film in infesting a piece of wood. Impractical as this test it, we believe it indicates information of value for the production of paints more resistant to termite attack.

The hardness of a paint film should be a factor in preventing termite infestation. An attempt was made to study this by using a series of paints made from asphalts of varying degrees of hardness. It was assumed that the paint, after thorough drying, had the same hardness as the original asphalt. Filter papers painted with these asphalt paints were included in the toxicity test of paints and the procedure was exactly as described above. Some interesting trends were observable, but the results are not conclusive. The softer asphalts were eaten less than the harder ones; the softer asphalts also seemed somewhat more toxic. There is also a slight trend in the series showing the hard asphalts to be a little less liable to attack than the soft ones. This series of asphalt paints indicates results which might logically be expected of any paint. A hard paint film should be more difficult to attack and penetrate than a soft one. On the other hand, a hard paint would be relatively inert, and the softer paints should show a higher toxic power.

Penetration of paint films; method of testing.—The test specimens used were small wooden dowels of redwood, Douglas fir, and sugar pine. The dowels were 3 inches (7.5 cm.) long and ½ inch (1.25 cm.) in diameter. A $\frac{3}{16}$-inch (0.3 cm.) hole was bored in the center about three-quarters through the length of the dowel, which was divided in half lengthwise to facilitate observations, and tapered at the end in which the hole was bored so that it would fit as a stopper into a small glass vial. The interior of the halves of the dowels, the surface of the hole in the center, and the outer surface of the tapered section were thoroughly coated with paint. Each of the forty-seven paints was applied to redwood, Douglas fir, and sugar pine dowels. Dowels were also prepared for each test with one, two, and three coats of the test paint. All paints were applied according to standard practice by an experienced painter. All dowels were allowed to dry for six months before they were subjected to termite attack. After this drying period there was probably none of the paint solvent left, and consequently fumigation from the paint did not affect the test results.

The insects chosen for this test of the penetration of paint films were the winged form, or recently dealated pairs of the dry-wood termite, *Kalotermes minor*. The recently mated reproductive pair of the dry-wood termite, during the swarming season, shows the greatest power to infest new material directly. Only mated pairs of the swarming dry-wood termite were used in this test. One pair was placed in a small vial and one of the painted dowels inserted as a stopper. The termites immediately entered the hole in the center of the dowel and had to cut through the paint film to reach wood for food. Daily observations were made to determine when the paint film was penetrated.

The natural mortality of new reproductive pairs is very high, and no significance can be attached to results which appear to indicate the relative toxic powers of the test paints. Because of the great difficulty of obtaining sufficient numbers of new reproductive pairs, all of the paints could not be tested, and those which were tested could not be retested several times to prove the results obtained. The results of this test cannot be treated exactly and only the general conclusions derived from them will be presented.

Three hundred and thirty dowels were used, representing twenty-six different paints. In eighty-one of these dowels, or about 24.5 per cent of the tests, the termites were able to penetrate the paint film. Close observations of these breaks in the paint film under a low power microscope show that the penetration was by mechanical scratching or eating of the paint film. There was no evidence of chemical action on the paint by excretions of saliva, and where fecal spots were left the paint film was found intact. This is represented in the microphotographs of some of the typical cases of penetration (fig. 124).

The dowel in figure 124*a* was given three coats of varnish. It shows clearly that the damage to the film was by gnawing.

In figure 124*b* the dowel had been given one coat of paint, a gilsonite paint. Here a clear-cut hole was eaten through the paint film. The white material is chewed-up wood removed as the insects dug into the wood.

The dowel in figure 124*c* was given one coat of aluminum primer and one coat of a lead-zinc paint. The dark spots with regular edges are fecal spots and

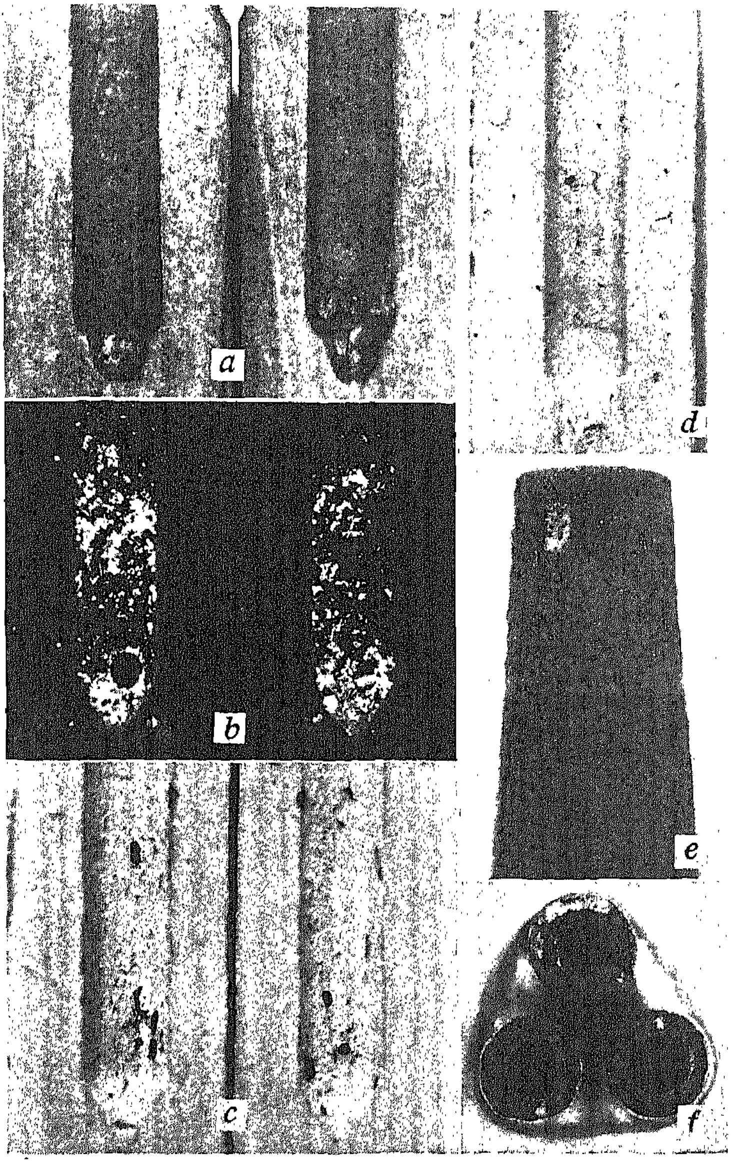

Fig. 124. Photomicrographs of typical cases of penetration of termites through paint films. *a–e.* Painted dowels. *f.* End views of three painted dowels.

not breaks in the paint film. A close examination showed that the paint film under these fecal spots was intact. Both the paint and aluminum primer had been scraped from the wood by the termites at the irregular dark spot shown near the lower inside edge of the right-hand half of the dowel.

Figure 124*d* shows a dowel which had three coats of paint. Under a microscope there was evidence of abrasion of the paint film at the vertex of the hole in the dowel, but the termites had not been able to break the film. The dark spot is a spot of fecal material, and it can be seen quite clearly that there has been no chemical action on the paint.

Figure 124*e* is of a dowel which was painted with three coats of paint. The termites wedged themselves between the glass vial and the tapered section of the vial to attack the exterior of the dowel. The paint was again gnawed and scraped from the wood, as shown at the white spot in the photograph.

Figure 124*f* shows an end view of three dowels coated with asphalt paints. The one at the top had two coats of paint, the one at the left one coat, and the one at the right one coat. The white spots show where the asphalt paint has been gnawed from the wood. It appeared typical with the asphalt paints that the termites preferred to attack them on the end grain of the wood.

Observations.—In general the time required to penetrate the paint film depended on the paint and the number of coats. The wood on which the paint was applied had practically no effect. The same paint, in the same number of coats, on redwood, Douglas fir, or sugar pine, was penetrated in approximately the same number of days.

The number of coats of paint evidently had an important bearing on the difficulty termites had in infesting wood through it. In twenty-two kinds of paint the termites were able to penetrate a one-coat film. In only eleven kinds of paint were they able to penetrate a two-coat film, and a three-coat film in only five kinds of paint. The same difficulty in penetrating thick paint coats is shown by the number of days required by the insects to penetrate the paint film. Here the results are very erratic, but they show in general about four days required to penetrate a single coat of paint, twelve days for two coats, and thirty days for three coats.

The series of asphaltic paints of varying hardness also showed that a greater time was required to penetrate the harder paints. This is in accord with the conclusions derived from the toxicity tests given above.

The most important point proved by this test was that termites are mechanically able to penetrate a paint film. The breaking of the paint film in no case involved chemical action in disintegrating the paint.

Susceptibility to infestation of painted panels; method of testing.—The panels used were of Ponderosa pine, 1 inch × 6 inches and 3 feet long (2.50 cm. × 15 cm. and 90 cm. long), surfaced on all four sides. Each panel was completely covered with paint on sides and ends, three thorough coats being applied by an experienced man according to standard practice. The panels were allowed to dry indoors for six months before they were used, in order to eliminate any effect from the odor or fumigating action of the volatile constituents of the paints.

Sixteen different paints were used in this experiment, most of which were chosen as typical standard paints found in general use. These paints, especially prepared for this test, were as follows:

No. 25 40–40–20 house paint
No. 26 flexible lacquer
No. 27 creosote shingle stain
No. 28 synthetic resin varnish
No. 29 cumar resin varnish
No. 30 gilsonite, china wood oil metal paint
No. 31 spar varnish
No. 32 coal-tar paint
No. 33 anti-fouling paint
No. 34 bituminous aluminum paint
No. 35 bituminous aluminum paint
No. 36 bituminous aluminum paint
No. 37 lead-zinc paint, with a lead-zinc priming coat
No. 38 lead-zinc paint, with an aluminum bronze-amberol varnish priming coat
No. 39 lead-zinc paint, with an aluminum bronze-aluminum mixing varnish priming coat
—A heat-treated china wood oil paint, containing ground glass and white arsenic. Paint of this exact composition was not included in the toxicity test.

Paints Nos. 37, 38, and 39 were those used in the tests of the paintability of treated woods.

Six panels were painted with each paint and twelve unpainted panels were included in the test as controls. The test was carried on at the plant of the Southern California Edison Company at Alhambra, California.

The panels were placed in an infestation test house, a small frame structure 8 feet × 15 feet (2.4 m. × 4.5 m.) and about 5 feet (1.5 m.) high, covered with cheesecloth. The panels were arranged in three ways. Two panels coated with each paint were clamped together with C-clamps; a sheet metal strip about 1/16 inch (1 mm.) thick was placed between them at each end to leave a small space between the panels; the two panels were then suspended from the roof of the enclosure. Two panels of each paint and four unpainted panels were suspended in this manner. The remaining panels were piled in eight stacks which were supported on hollow building tile to keep them off the ground. In four of these stacks sheet metal spacers 1/16 inch (1 mm.) thick were placed between adjacent panels, and in the other four stacks the panels were piled directly one upon another. The ninety-six painted panels and the twelve unpainted panels were placed in the test house in a careful disarrangement of pairs of like panels, so no local condition in the test house or in the panel groupings would affect the test.

The panels were arranged in the infestation test houses early in September before the swarming period of the dry-wood termite. A number of sections of poles and timbers known to be heavily infested with the dry-wood termite were placed among the stacks of panels and scattered generally throughout the enclosure. The enclosure was not inspected until late in January, when the swarming of *Kalotermes* appeared to be over.

Observations.—Upon inspection the termite infestation was found not so heavy as anticipated. Some of the winged forms of the dry-wood termite had escaped through the cheesecloth, and many others had established themselves in the rough lumber of the framework of the enclosure. None of the painted panels were found infested by the termites. Every pair of unpainted panels was infested, regardless of its position in the test house. The infestation in the panels was judged by the presence of holes plugged with soft chewed-up wood, which indicate infestation by the colonizing pairs of the winged form of *Kalotermes minor*. Each such hole indicates the presence of one colonizing pair, and the unpainted pairs of panels each showed from one to eight such holes.

This experiment proved that painted wood is highly resistant to termite attack if there are no breaks in the protecting paint film. All paints included in the test showed resistance to termite infestation. A comparison of the relative protection afforded by each of the paints could only be made if no unpainted wood were available to the termites.

We wish to acknowledge the cooperation we have had from the Paraffine Paint Companies in the preparation of all the painted specimens for the tests of the Committee.

FIELD TESTS AND OBSERVATIONS

Field observations showing the infestation of wood through paint films in good condition have been very scarce. Infestations through paint films broken by weathering, checking, or mechanical damage are not uncommon. Practically all reported cases of termite infestation through paint were traced to an imperfect paint film. Many cases of well painted wood infested with termites were found, but the infestations had not occurred through a painted surface. Often the infestation was from the back of the board, which was not painted, or from another infested board in direct contact with the painted one.

A small test house was built by the Committee in a large infestation enclosure and subjected to attack by swarming dry-wood termites. Part of the exterior lumber of this house had been given a light priming coat of paint. Several cases of infestation of this lightly painted wood, directly through the paint on smooth surfaces, were observed. This is the only conclusive case of infestation through an unbroken protective paint film which has come to our attention.

The San Diego Consolidated Gas and Electric Company reports that prior to 1923 they encountered considerable infestation by the dry-wood termite of wooden insulator pins and crossarms which had been painted. Since that time they have been using paint poisoned with ½ per cent white arsenic on pins and crossarms. They state that termite damage to these wooden materials has been practically stopped by the use of these poisoned paints. These crossarm paints containing white arsenic were tested in the toxicity tests of paints under Nos. 71 and 72.

Paints have been tested for the extermination of termites in infested wood both by the Committee and by the San Diego Consolidated Gas and Electric Company. All tests of this type were made on pole sections infested with the dry-wood termite. Some of the paints tested were *Moran's Wood Preservative Paint,* a poisoned paint; *McEverlast's Termite Special,* a gilsonite paint containing about 5 per cent of powdered sodium arsenite; *Hill-Hubbel Cement Paint,* and several others. The painted stubs were inspected from three to six months after treatment. On inspection, the termites in the central galleries were found to be unharmed. Where the paint was applied generously it often ran into the surface galleries and killed the few termites with which it came in contact. Paint applied to the surface of infested wood has no value for exterminating the termites within it.

PROTECTION OF WOOD-PRESERVATIVE TREATMENTS BY PAINT

As far as we have been able to learn, there is no definite information available on the protection afforded wood-preservative treatments from leaching. A few general remarks on this subject seem worth while. We are indebted to Mr. George M. Hunt, of the Forest Products Laboratory, for some of the ideas expressed.

Paint allows absorption of moisture by wood through the film but protects the wood from direct washing by rain. When the preservative material is not soluble in the linoxyn of the paint film (as would be the case with salt preservatives), the film probably acts as a semi-permeable membrane. The moisture may pass through, but the film does not allow the salt material to pass through it even when it is in solution.

It appears at first that paint should increase the permanence of all preservative treatments. This is probably true to a considerable extent, but is not so evident for preservatives containing oil and organic chemicals as it is for salts. Preservatives which are soluble in the linoxyn of the paint film will be absorbed from the wood into the paint. Here they are more readily reached by moisture, and, if somewhat soluble in water, may be easily washed from the painted surface. However, if this took place to any great extent there should be some evidence of it in the paint film or at the lower end of the panels, where there should be a concentration of any appreciable amount of preservative washed out.

Observations on painted and unpainted panels treated with the preservatives used in the test of paintability showed in most cases a visible leaching of the preservative from the top of the unpainted panels and, in the early stages, increased concentration of the preservative at the bottom. No such effect was observed in the painted panels either visually or by increased deterioration of the paint at the lower ends of the panels. It seems quite safe to conclude in general that paints have afforded protection to the preservative treatments over which they were applied.

COOPERATIVE STUDY BY CALIFORNIA PAINT SUPERINTENDENTS CLUB OF PAINT DURABILITY OVER PRESERVATIVE-TREATED WOODS

The California Paint Superintendents Club, in cooperation with the Subcommittee on Chemistry of the Termite Investigations Committee (Circular 404, Scientific Section, Educational Bureau, American Paint and Varnish Manufacturer's Association, December, 1931), undertook a brief study of paint durability over preservative-treated woods, the obvious purpose being to find preservative treatments for wood that would prevent destruction by termites and leave the wood in a paintable condition. Records available on work of this kind are scanty. Some work has been done by H. A. Gardner (1931) on painting over wood treated with zinc chloride, and by M. E. Dunlap (1926) on painting over miscellaneous treatments. Final results have not as yet been published by Mr. Dunlap.

An investigation of commercial wood preservatives led to the selection of eight kinds for painting tests: *Ac-Zol, Anaconda Neutral, Bruce Preservative 5A, Halowax, Lignophol, Wolman Salts (Triolith), Zinc chloride,* and *Zinc-Meta-Arsenite.* The panels were prepared by the Committee and treated in plants designated by the manufacturers and according to their specifications. Creosote treatment was not studied, but we give in the next section a brief account of experiments by the Aluminum Company of America. To further broaden the scope of the work it was decided to use three western species of wood, treated and painted in identical manner. The wood species selected were redwood, Douglas fir, and Ponderosa pine. The panels were 1 inch × 6 inches × 18 inches (2.5 cm. × 15 cm. × 45 cm.), cut from ordinary common lumber, each piece containing a sound knot, with no attempt made to select or match panels. This was done to make the test as practical as possible. This procedure had little or no influence on the final average result.

Test fence and exposure of panels.—The test fence used for the exposure of panels was located on the campus of the University of California at Berkeley, and being situated on the sharply rising ground at the south end, provided a clear, unobstructed southwest exposure at an elevation of several hundred feet above sea level. The fence itself was approximately 200 feet in length and was constructed by sinking posts carrying supports attached at an angle of 45 degrees and spaced equally for the length of the fence. At the end of twelve months the summary of the several inspections indicated very small differences in paint durability over variously treated woods.

Of all the preservatives studied only zinc chloride and one proprietary preservative showed distinctly deteriorating influences on any of the paints used, and of these only the proprietary preservative can be said to be definitely unpaintable. The manufacturer does not recommend this preservative for service where the lumber is to be painted. It was studied as an example of a preservative which leaves a permanently "oily" surface after treatment.

There seems to be very little choice between kinds of finish used. The two aluminum primers show some advantage over lead and zinc, especially in the case of *Ac-Zol* treated Douglas fir and redwood, and zinc chloride treated Douglas fir and Ponderosa pine. *Halowax Bakelite* painted panels are shown to be just a trifle inferior to the *Halowax* panel painted with aluminum primers, although *Halowax* can be said to be paintable with any of the finishes used. The species of wood tested had little or no influence on the relative paintability of the preservatives.

At the end of fifteen and a half months another inspection of the test panels was made. Because of marked changes that occurred between twelve and fifteen and a half months' exposure, it was necessary to modify some of the original conclusions. Weather conditions during July, August, September, and October were undoubtedly such as to cause faster destruction of paint films than exposure during the first year of the test. It was obvious that between the twelve and fifteen and a half month periods greater differences developed among the paints on the different preservative treatments; for example, it had become more obvious that some treatments had distinctly destructive effects on the paint films.

However, it was still possible to say that the majority of treatments were paintable, and, in fact, the paint over most of the treated woods was found to be in as good or better condition than the same paints on untreated wood. With the exception of Halowax Corporation special tests, untreated painted woods were all close to 2.3 rating, being, therefore, in fair condition. It was probably more than a coincidence that *Triolith* and *Lignophol* treated woods showed a distinct tendency to add life to paint over them. *Halowax No. 1012* also seemed to add life to the paint when aluminum primers were used, but it had a very definite destructive effect on lead and zinc primers.

As at the end of the twelve months, the fifteen and a half month inspection showed aluminum primers to be generally better than lead-zinc. In particular, aluminum primers were better for *Ac-Zol* treated Douglas fir and redwood and zinc chloride treated Douglas fir and Ponderosa pine.

The special Halowax Corporation tests are very interesting in that the Bakelite paints show superior durability, even after discounting the small handicap given them by a late start. The condition of these Bakelite paint films was more remarkable than is indicated by their ratings at fifteen and a half months. They all showed slight chalking with microscopic checks, which normally would have been rated close to perfect but for a very marked inclination to peel back from the edges of the panel. This fault, of course, reduces protection. This peeling occurred on both treated and untreated panels.

The wood treatments that caused marked paint failures also caused a type of failure that is undesirable for repainting. In all cases, failure started with deep checking followed by partial flaking off. Normal failure of the paints used starts with shallow checks and chalking.

These tests probably show accurately the relative paintability of the wood preservatives used. The majority of the paint panels were still in fairly good condition at the last inspection.

It is interesting, also, to note the real need for paint protection of preservative impregnated woods. Unpainted preservative impregnated panels and untreated panels were also exposed with the painted panels. In all cases, except oily treatments, the preservative failed to retard deterioration of the wood surface and some of the preservatives actually hastened deterioration. *Bruce 5A* and *Lignophol* have a slight retarding effect on weathering of unpainted wood. As has already been observed, the painted treated woods compare favorably in durability with painted untreated woods.

THE PAINTING OF CREOSOTED WOOD

The need for a paint coating which will satisfactorily cover and "seal" lumber impregnated with creosote or similar preservative has long been felt by industry. Creosote in lumber has a marked tendency to "bleed" through or discolor most paint coatings applied to the surface. For a number of years paint technologists and lumbermen have attempted to secure a satisfactory paint coating with only limited success.

Tests by the Aluminum Company of America indicate that creosoted wood panels coated with two coats of aluminum paint made with spar varnish vehicles show very little bleeding after three years' outdoor exposure, the paint film being sound, showing no checking or flaking.

In October, 1928, a series of tests on creosoted posts was started by the Aluminum Company of America in cooperation with the National Lumber and Creosoting Company. These tests were conducted at Houston, Texas. Over fifty creosoted southern yellow pine posts were included, half of which had been freshly creosoted prior to the test, and the remaining half selected from stock which had been allowed to weather for several months prior to painting. The type of creosote impregnation was not definitely stated, but it is assumed that the typical impregnation given to telephone poles was used for this work. Six different types of vehicles were used for the aluminum paint in coating these posts, and two and four pounds of aluminum powder were used per gallon of each vehicle. The posts were placed in the ground and the exposed portion was given a single coat of aluminum paint. All posts which showed bleeding tendencies within three weeks were then given a second coat of the same aluminum paint. In this way many combinations of vehicle, powder, number of coats, and kind of posts were included.

After one year's exposure an inspection of these posts was made and it was found that in practically all cases the aluminum paint on posts which had been allowed to weather before painting was still in excellent condition, regardless of the type of vehicle employed or the amount of powder used. In many cases a single coat of aluminum paint had been sufficient on this type of post. It would therefore appear that no great difficulty should be encountered in painting creosoted wood which has been allowed to weather sufficiently to remove free creosote from the surface of the wood.

Over half of the freshly creosoted posts showed marked signs of failure, however, after one year's exposure. Those which were still in satisfactory condition had been coated in most cases with aluminum paint made with four pounds of powder per gallon. The results obtained with the various vehicles on the freshly creosoted lumber were somewhat erratic. One of the chief conclusions to be drawn from this test is the necessity of allowing a weathering period for the creosoted material before applying any paint coating, and even then, in some cases, two coats of paint may be required; the use of more than two pounds of powder per gallon of vehicle does not appear to be necessary. It was also found that indications of bleeding will appear within a few months if bleeding is to occur. None of the posts reported to be in good condition after two months showed any marked signs of bleeding after one year.

Perhaps the greatest need for paint coatings on creosoted wood is found on telegraph or telephone poles, highway guard rails, and similar types of construction along the highway. A number of state highway commissions have conducted experiments with aluminum paint for this purpose with very satisfactory results. They have found, in general, just as pointed out from the foregoing tests, that a substantial weathering period should be allowed before attempting to coat a creosoted post.

For painting creosoted wood the vehicle for aluminum paint should be carefully selected. Tests have shown that a fairly hard drying spar varnish type of vehicle is preferable. Such a vehicle should contain a substantial portion of China wood oil; it should make a paint of good brushing consistency when mixed with two pounds of powder per gallon of vehicle; it should contain approximately 50 per cent non-volatile matter and pass a 60 per cent Kauri reduction test; and it should set to touch in two hours and dry hard in fifteen to eighteen hours. Recent experiments have shown that some of the newer synthetic resin varnishes are quite satisfactory in this respect, particularly those made with oil-soluble Bakelite resins. Such varnishes might also have a slightly toxic effect on fungus growth and other agencies destructive to wood.

OBSERVATIONS

The results of the Committee's tests and observations on the use of paint in termite control indicate that paint is valuable only in connection with the dry-wood type of termite, which infests wood directly from the outside.

1. Paint is not effective for exterminating termites in infested wood.

2. A well applied, continuous paint film makes wood highly resistant to dry-wood termite attack. However, termites can readily infest wood through a broken or checked paint film.

3. Termites can penetrate through a paint film to infest the wood it covers, but this is not a general occurrence. Wood thoroughly protected by paint cannot be said to be termite-proof, but its termite resistance is undoubtedly materially increased over that of comparable untreated wood.

4. A paint film, properly applied and adequately maintained, will certainly discourage attack by dry-wood termites.

5. For preservatives which give the desired protection paints are available which can be used without serious damage to the paint treatment by the preservative. Not all architectural effects can be achieved, but where the

architectural requirements are paramount a slightly less permanent preservative can be used to advantage. Some preservatives give a pleasing architectural effect without paint and withstand the effects of weather. Creosote-treated timber can be painted with aluminum paint, although the life of the aluminum paint film is shortened by the creosote.

CHAPTER 38

POISON DUSTS

I. TREATMENTS WITH POISONOUS DUSTS

BY

MERLE RANDALL AND THOMAS C. DOODY

In a report on termites from Porto Rico, Van Zwaluwenberg (1916) states that in the case of *Nasutitermes morio* (Latreille), which has habits similar to those of the subterranean termite, *Reticulitermes hesperus* (Banks), in California, "A very cheap and efficacious control of this pest is obtained by placing liberal quantities of any powdered arsenical poison in the runways and the nest. The insect's habits insure the spread of the poison throughout the colony and the nest is killed out completely in from one to three days. London purple gives quicker results than Paris green, probably because of the finer division of the particles." A recent note (*in litt.*) from Mr. Van Zwaluwenberg states that this use of Paris green was not original with him. Although the exact source of the plan has been forgotten, it seems to have come from one of the entomological reports from one of the smaller British West Indian islands. A later publication of termite studies in Porto Rico by Wolcott (1924) tells of the use of Paris green for *Nasutitermes morio*. He says, "Breaking open the top of the nest or, if this cannot be found, the main tunnels, and placing about a tablespoon of any stomach poison—Paris green, arsenate of lead, and calomel have all been used successfully—in it, will completely destroy the colony."

Although poisonous dusts were used for controlling wood-dwelling termites before 1928, the importance of the treatment was not appreciated. In the Orient poison dusts were applied to infested buildings by blowing large quantities between the walls and into the attic space. This treatment was unsatisfactory and extremely dangerous to the occupants of the dwelling as small quantities of the poison were continually sifting through cracks in the wall and ceilings into the living quarters of the house. The modern application of dust poisons to termite control which has proved relatively safe, efficient, and economical was brought to our attention through lectures in California by Mr. E. M. Ehrhorn, of Hawaii, correspondence with Dr. T. E. Snyder, of the U. S. Bureau of Entomology, and reports on work by F. P. Jepson on the control of termite damage to tea bushes in Ceylon through the use of Paris green, as suggested by Dr. Snyder. It was difficult to realize that a small quantity of arsenical dust placed in the galleries of the termite colony would give effective control and kill the insects even in the most remote chambers.

The biological information on the means by which this simple treatment becomes effective was lacking.

Laboratory studies of dust poisons.—The first work in the laboratory was to place the termites (both the subterranean termite, *Reticulitermes hesperus,* and the dry-wood termite, *Kalotermes minor,* were used) in dishes containing the powdered poisons, for observation. All termites which came in contact with the poisons died in a few days. They showed a strong dislike for contact with the fine powder which stuck to their bodies, and tried to remove it. Other termites at first avoided those which carried the powdered poison on their bodies, but eventually groomed them. The experiments were extended by dusting a few termites with the powdered poisons to act as carriers, and putting them in with a larger group of normal insects. In these tests both dusted and normal termites died, indicating that the poison might be carried throughout the nest effectively.

The laboratory work on dust poisons was expanded by the Subcommittee on Biology. *Zootermopsis angusticollis* was used for most of this work. Tests of the toxicities of various dust poisons with nymphs of the damp-wood termite showed comparative time of death for a total of twenty-five insects. The time required to kill all twenty-five termites is shown below.

1. Five insects were dusted and 20 were normal.

Arsenical smelter dust	12 hours
Paris green	60 hours
Sodium fluosilicate	57 hours
Flu-si-dust 70% sodium fluosilicate, 30% inert	143 hours
Borax	170 hours
Barium fluosilicate	211 hours

2. One individual out of 25 dusted.

Arsenical smeltor dust	18 hours
Paris green	384 hours
Sodium fluosilicate	102 hours
Flu-si-dust 70% sodium fluosilicate, 30% inert	187 hours
Calomel (mercurous chloride)	238 hours
Borax	305 hours
Cryolite (sodium aluminum fluoride)	360 hours
Barium fluosilicate	355 hours

Typical results of the study of termites as carriers for the poison dust are shown in the tests with arsenical smelter dust on nymphs of *Zootermopsis angusticollis.*

5 dusted out of 25	all killed in 12 hours
1 dusted out of 25	all killed in 18 hours
1 dusted out of 50	all killed in 30 hours
1 dusted out of 100	(*a*) all killed in 40 hours (*b*) all killed in 30 hours
1 dusted out of 150	all killed in 30 hours
1 dusted out of 250	all killed in 32 hours

The arsenical smelter dust was the most toxic material investigated; nevertheless, it was remarkable to find that 1 insect could carry enough poison on its body to kill 249 others. In control tests it was possible to keep the normal termites alive for several months.

The grooming of the poisons from the dusted insects plays an important part in the effectiveness of this treatment. However, even where there is no possibility of grooming, all insects are killed, due to the spread of the poison over the floors of the test cages where the dusted termites have walked. In later field tests with Paris green the wide distribution of the poison throughout the termite galleries was revealed by the green color.

The laboratory toxicity tests showed the dust poisons effective with the dry-wood termite, *Kalotermes minor*, the damp-wood termite, *Zootermopsis angusticollis*, and the subterranean termite, *Reticulitermes hesperus*. Under field conditions, however, the dust treatments were thoroughly satisfactory with the dry-wood termite only. Dusts were effective with the damp-wood and subterranean termites only under particularly favorable conditions.

Effect of size of dust particles.—In both laboratory and field tests the size of the dust particles was found to be an important factor in the effectiveness of dust treatments. The commercial grade of white arsenic is a granular powder, and it was not nearly so effective as the arsenical smelter dust, which contains the same material in a very finely divided form. The latter is extremely fine, and 95 per cent or more will pass through a 300 mesh per inch (120 mesh/cm.) screen. Particles of the commercial grade of sodium fluosilicate were estimated at about 80 mesh (32 mesh/cm.). Its effectiveness was greatly increased by grinding it to finer than 200 mesh per inch (90 mesh/cm.). The small dust particles give a more effective and efficient dust treatment than larger poison grains, because of the fact that they are much better adapted in size to adhere to and to irritate the microscopic sensory hairs of the termite.

Method of application.—The basis of the dust treatment is to place a finely powdered dust poison in the termite galleries where the insects will come in contact with it. The treatment will be effective more quickly if a wide distribution of the poison is obtained through the termite galleries by the method of application. This is not necessary, however, as the insects distribute the dust poisons through their galleries more thoroughly than has been found possible by any method of application.

The dust poisons are blown into the termite gallèries by suitable dust guns (fig. 125) through holes bored into the infested wood. The size of the holes will depend on the sizes and types of timber to be treated. For large timbers and poles a hole about ½ inch (1.3 cm.) in diameter is recommended. For finished woodwork and interior trim a hole as small as $\frac{1}{16}$ inch (1 mm.) in diameter may be used satisfactorily. The hole should be bored deep into the infested wood, half way or more into the largest dimension of the timber. This increases the chance of cutting into termite galleries. With practice the operator can tell when the bit is boring into termite galleries.

The spacing of the holes for treatment is a point which must be decided for each individual case. Experience shows that one application of the dust poison into the galleries of each colony will usually give complete control. However, in one timber there may be several small but entirely separate colonies, each one of which will have to be treated with the dust. In poles, complete control has been obtained to as far as 15 feet (4.5 meters) from the hole where the dust was applied. Other cases have shown unaffected small colonies within 6 inches (15 cm.) of the application of the dust treatment. The usual recommendation has been to treat the infested timber every 3 feet (90 cm.), if this can be done without undue damage to its strength. It is advisable to make periodic inspections, about every six months after the application of the dust treatment, to see that there are no small isolated colonies which have escaped the poison. A very small quantity of the poison dust is required for an effective treatment. One ounce (28 gm.) of the poison should treat fifteen to thirty holes, depending upon the size of the timber.

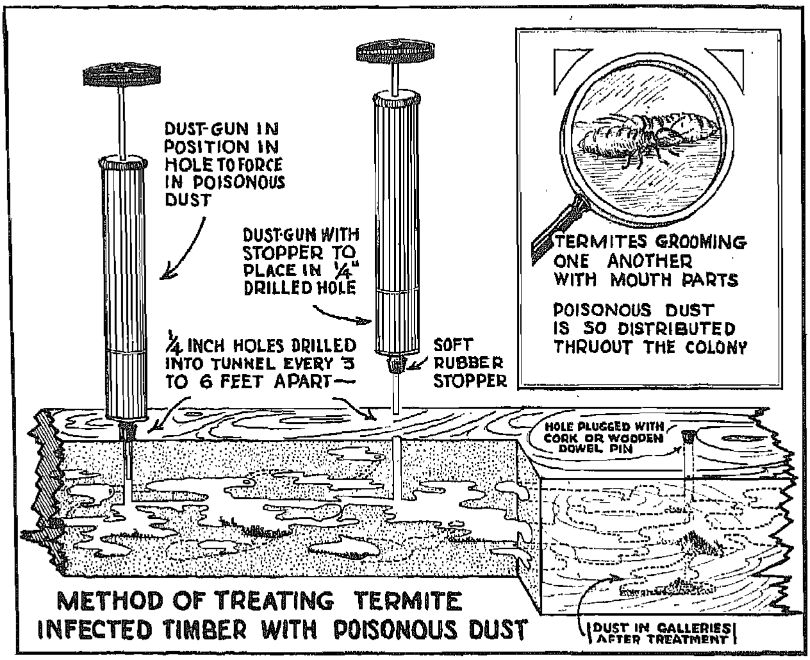
DUST-GUN IN POSITION IN HOLE TO FORCE IN POISONOUS DUST
DUST-GUN WITH STOPPER TO PLACE IN ¼" DRILLED HOLE
¼ INCH HOLES DRILLED INTO TUNNEL EVERY 3 TO 6 FEET APART—
SOFT RUBBER STOPPER
TERMITES GROOMING ONE ANOTHER WITH MOUTH PARTS
POISONOUS DUST IS SO DISTRIBUTED THRUOUT THE COLONY
HOLE PLUGGED WITH CORK OR WOODEN DOWEL PIN
METHOD OF TREATING TERMITE INFECTED TIMBER WITH POISONOUS DUST
DUST IN GALLERIES AFTER TREATMENT

Fig. 125. The dry-wood termite once established may best be combated by means of poisonous dusts spread through the colony by the termites themselves. Termites have a habit of grooming one another, thus transferring dusts one to the other. The best methods known at present for applying such dusts are illustrated above. From *Calif. Agr. Exp. Stn. Circ. 318, fig. 31.*

After the dust is blown into the termite galleries the holes must be sealed with dry wooden dowels. This apparently minor point is an essential part of the treatment, since, if the hole is sealed, the termites continue to use the galleries containing the poison, showing no fear of the treatment; if the hole is left open they seem to realize some danger and block off the galleries opened by the treatment. Furthermore, the practice of closing the holes after treatment seals the poison in the wood, where human beings will not come in contact with it, thus removing a possible danger to health from the use of these dust poisons.

Types of dust guns.—The dust gun found most satisfactory for general use by the Committee is a small *hand type* of duster made for garden use. The type with the dust chamber forming an extension of the air pump barrel and with the nozzle in line with the pump is found convenient (fig. 126). The gun, which is made of sheet metal, is about 2 inches (5 cm.) in diameter and less than 2 feet (60 cm.) in length. This type of duster is readily obtained from retail hardware or insecticide dealers at 50 or 60 cents each.

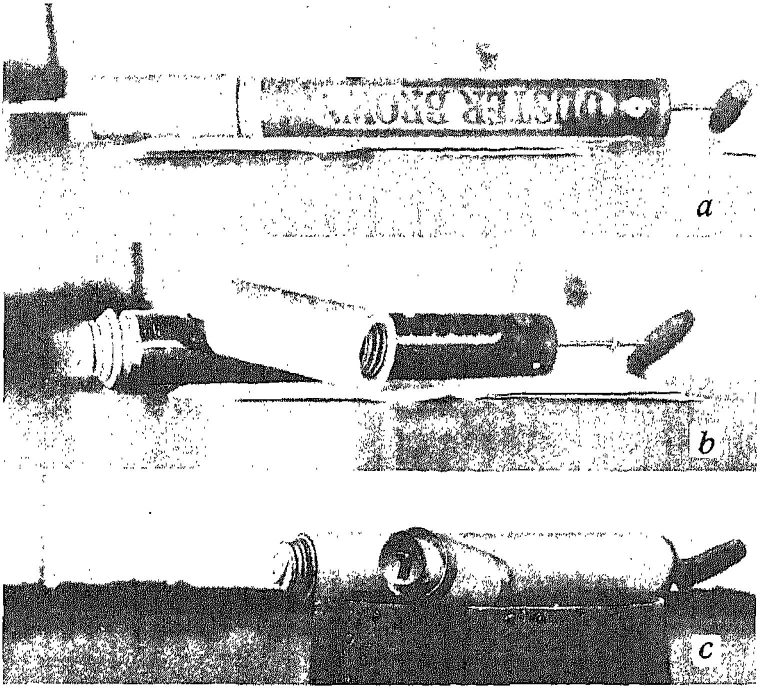

Fig. 126. *a.* Typical dust gun, complete. *b.* Dust chamber removed for loading. *c.* Nozzle cut off and fitted with rubber suction cup.

The nozzle of this hand gun should be changed for the application of dust poisons for termite control. A small rubber suction cup of the kind used for holding ash trays, show cards, etc., on glass should have a hole bored through it and be placed on the ¼-inch pipe nozzle of the gun. Place the rubber shoulder on the back of the suction cup firmly against the top of the dust chamber. The pipe nozzle of the dust gun should then be cut off, leaving only about ¼ inch (0.6 cm.) of it projecting beyond the inside surface of the suction cup (fig. 126*c*).

This short spur nozzle with the rubber suction cup makes a good air-tight seal on the timber surface around the hole to be treated with the dust poison, and allows the dust to be blown into the termite galleries under pressure without any danger of the poison blowing out into the face of the operator. The short spur nozzle makes certain that the dust is being blown directly into the hole. With this type of seal even the galleries near the surface, or in the sapwood of poles, are left open to treatment by the dust. The dust gun was, at first, sealed into the hole to be treated with a soft rubber stopper, but this closed off the galleries near the surface so that the surface galleries did not receive any dust during the treatment, causing failure where the surface wood only was infested. This objection was overcome by the short nozzle and suction cup.

In using this hand type dust gun in field tests with Paris green it was noticed that the air pressure would often force the Paris green through the galleries of the dry-wood termite for about a foot from the point of treatment. This seemed to give a very satisfactory treatment.

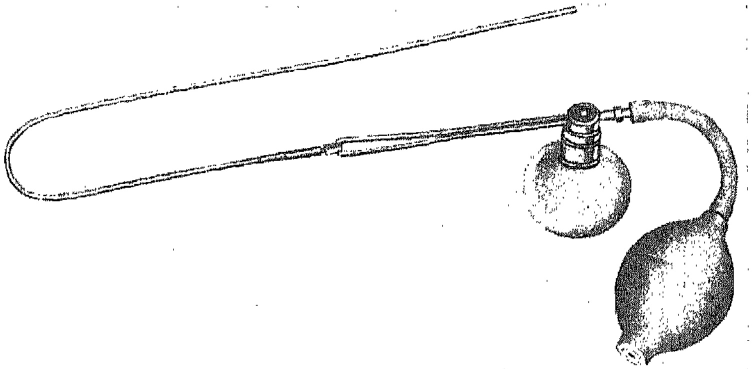

Fig. 127. De Vilbiss atomizer No. 79 with copper tube extension used as dust gun in experiments at University of California Citrus Experiment Station, Riverside, California.

The experiments performed with poison dusts for termite control by Dr. Ralph H. Smith (1930) at the Citrus Experiment Station at Riverside, California, were done with a dust gun of the *atomizer type* (fig. 127). The instrument was made of atomizer No. 79, manufactured by the De Vilbiss Company, Cleveland, Ohio, which can be obtained through any drug store. A piece of flexible copper tubing $5/64$ inch (0.2 cm.) in diameter was placed on the nozzle in order to apply the dust to points which could not be reached with the regular nozzle. The poison dust can be injected into the termite galleries through a very small hole, which can be so carefully sealed as to be practically invisible.

A special type of dust gun for the application of the poison dust treatment under *pressure* was designd by the Municipal Light and Power Department of the City of Pasadena under the direction of Mr. B. F. DeLanty, for the purpose of treating poles infested with the dry-wood termite, the dust to be applied at an air pressure of 70 to 75 pounds per square inch (4.9 to 5.2 kg./sq. cm.) (fig. 128). The tapered nozzle has a steep pitch wood screw thread so the gun can be set quickly and firmly in a ½-inch (1.3-cm.) hole bored in the infested wood. Air shut-off valves are placed both in front and behind the dust chamber, which has a large screw capped side opening through which it is charged. The air pressure is supplied from a small compressor on a truck and enters the dust chamber through a tube with small holes in the side. This agitates the dust in the chamber so that a mixture of air and dust is blown into the termite galleries. Experiments with this gun showed that Paris green could be blown through the galleries of the dry-wood termite for a distance of 2 feet (60 cm.) from the point of treatment. This gun has been very satisfactory for large scale treatments. The main objection to it is its cost and the equipment required to run it. The gun alone, which had to be made specially, cost about $16.00.

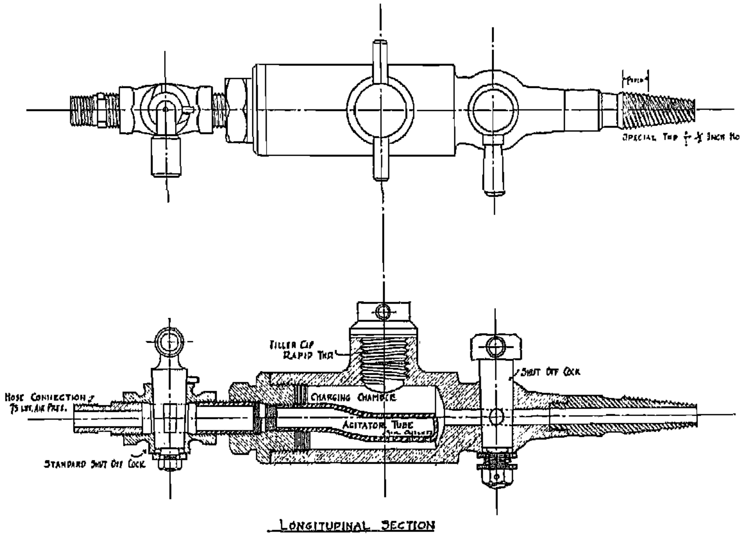

Fig. 128. Power dust gun designed by the Light and Power Department of the City of Pasadena, California, for use on poles.

As mentioned above, the most satisfactory gun for the general application of dust poisons is the hand type dust gun. The equipment is cheap and effective. The suction cup nozzle also has advantages over those found in the other types of guns discussed.

Poison dusts and precautions to be observed in their use.—Only those dust poisons which were practical from an economic standpoint were used extensively in field tests. The materials in which the greatest interest was shown were Paris green, arsenical smelter dust, sodium fluosilicate, and barium fluosilicate.

Paris green, which is copper aceto arsenite, is a very fine powder and is well adapted to dust treatments. It retails for from 40 to 45 cents a pound, depending on the quantity bought. It has long been used as a dust insecticide and the danger of handling it is well understood. The brilliant green color of the dust calls striking attention to it and gives warning of the presence of the poison.

Arsenical smelter dust is a mixture of arsenic oxides recovered from smelter fumes. The average composition runs 98 per cent arsenic oxide with 85 per cent arsenic trioxide and 12+ per cent of arsenic pentoxide. Although not readily available on the market in small quantities, the material is cheap, costing only 6 to 8 cents per pound. Arsenical smelter dust was the most toxic of the poison dusts tested with termites and should be handled with care. The dust is extremely fine, most of it passing through a sieve of 300 mesh to the inch (120 mesh /cm.).

Sodium fluosilicate, or sodium silicofluoride, is usually listed as a nonpoisonous material and has in the past been used in Europe as a food preservative. The material is an irritant and should be handled carefully, although there is little danger of poisoning. The commercial grades of sodium fluosilicate come as a coarse granular powder, which costs at retail from 16 to 20 cents a pound. For use as a dust poison the commercial sodium fluosilicate should be ground fine enough to pass through a 200 mesh (80 mesh /cm.) screen.

A commercial product manufactured by Michel and Pelton Company of Oakland, California, under the trade name *Flu-si-dust*, was tested. The grade used for termite control consisted of 70 per cent sodium fluosilicate and 30 per cent inert ingredients (diatomaceous earth). It had no advantages over pure sodium fluosilicate for dust treatments and was not so toxic, due to dilution with inert ingredients.

Barium fluosilicate is probably somewhat more poisonous to man than sodium fluosilicate, although it is less toxic to termites. It is only very slightly soluble in water and shows little tendency to cake in damp wood. Barium fluosilicate is a very fine powder and costs about 20 cents per pound.

Precautions.—For the safe handling of poisonous dusts, cleanliness should be observed before and after handling the dusts. Do not breathe the dusts, or get them on clothing and body. Change clothing and wash thoroughly in plenty of water after using them and before eating, drinking, or smoking. Should some of the dust be accidentally swallowed, particularly if it is either arsenical smelter dust or Paris green, give emetics and call a physician. As a precautionary measure, linemen treating poles with poison dusts should be equipped with goggles and dust filter respirators.

Field tests on the dry-wood termite.—One of the first field experiments made by the Committee with the *Paris green* dust treatment was in sections of red cedar poles infested with the dry-wood termite. The Paris green was applied with the hand type dust gun and was blown into ½-inch (1.3-cm.) holes 6 inches (15 cm.) deep, bored into the poles in varying radial directions at 3-foot (90-cm.) intervals. It took 2 ounces (56 gm.), or about 5 cents' worth of Paris green to treat a 30-foot (9-m.) pole. Two smaller pole sections and half of the 30-foot (9-m.) pole were cut open and inspected one week after treatment. Both live and dead termites were found. Dead termites were found both with and without Paris green on their bodies. The results of this inspection were not discouraging, as it was already known from laboratory tests that when only one termite out of twenty-five was dusted with Paris green sixteen days were required for complete kill. The half pole which was saved was inspected six weeks after treatment, at which time all the termites were found killed by the Paris green. To make certain that the termites had not been killed by unfavorable climatic conditions, infested but untreated poles in the same pile were inspected. The termites found in them were alive and normal, thus proving that the deaths were due to Paris green.

Two other pole sections, one an 8-foot (2.4-m.) section of Douglas fir, and the other a 12-foot (3.6-m.) piece of red cedar, were treated with Paris green dust in the same way. The treatment was applied every 3 feet (90 cm.). The two test pieces took 3 and 5 cents' worth of Paris green, respectively, and required slightly less than one hour each for treatment. They were cut open and inspected ten weeks later; all the termites in each had been killed by the Paris green.

The Paris green dust treatment was next applied to a 35-foot (10.5-m.) red cedar pole in service, which was badly damaged by the dry-wood termite. Six ½-inch (1.3-cm.) holes were bored 3 feet (90 cm.) apart, the highest one being about 18 feet (5.4 m.) above ground. Paris green was blown into each hole with the hand type duster and the holes were sealed after treatment. The treatment took 2 ounces (56 gm.) of Paris green, or about 5 cents' worth, and required the time of two men for forty-five minutes. The total cost of treating was about 80 cents. This pole was removed from service and inspected six months later, at which time all the dry-wood termites in it were found dead, even throughout the top of the pole, to a height of 15 feet (4.5 m.) above the nearest application of poison. The pole had been badly damaged by the insects and was fairly porous (fig. 129). The distribution of the Paris green dust by the hand duster was found in some cases to be as much as 2 feet (60 cm.) from the point of application. Live subterranean termites were found in the butt of this pole. They were apparently not affected by the treatment applied just above the ground line. This is due to the fact that the galleries of dry-wood termites are not found to be connected with those of subterranean termites near the ground level. At this point the two types of galleries may pass each other, but each avoids connection with the other.

In these groups of tests, microscopic examinations showed that small quantities of Paris green had been transported throughout the termite galleries by the termites themselves. It was found impossible to obtain as thorough a distribution of the dust poison by any mechanical means.

In the tests made by Smith (1930) at the Citrus Experiment Station at Riverside, California, the atomizer type dust gun was used to apply Paris green to wood infested with the dry-wood termite. Two window sashes, some floor board, and siding were treated. The treatment was applied only at the lower end of the window sashes. This material was removed and inspected fourteen months after the treatment. All termites in the treated ends of the

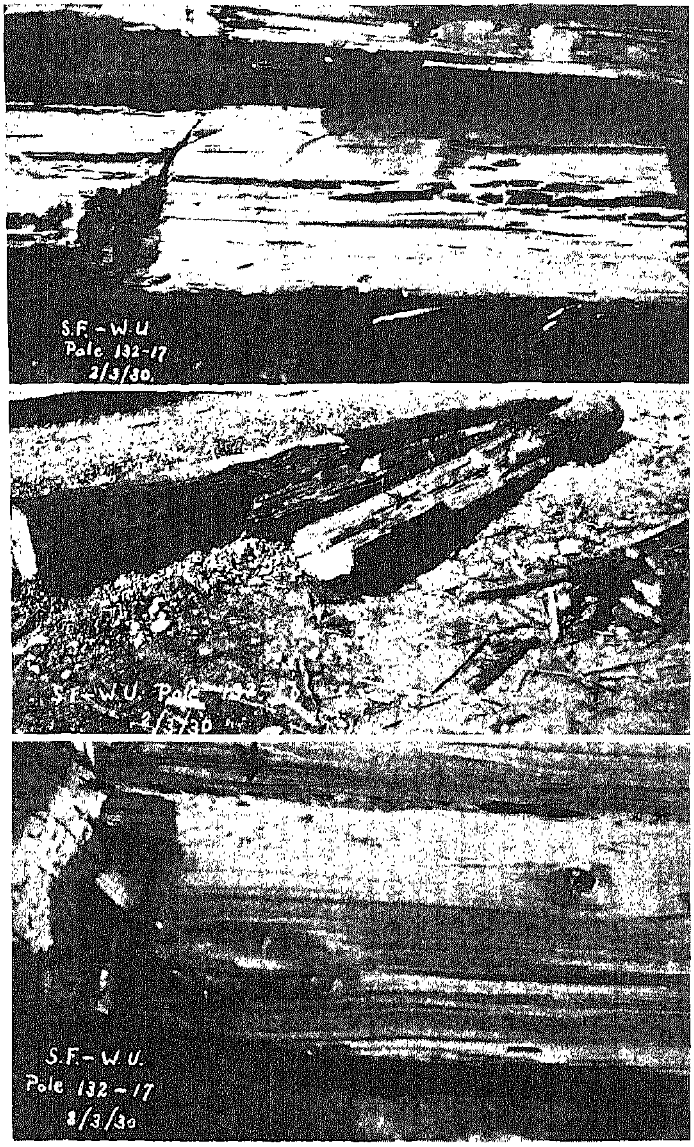

Fig. 129. Application of Paris green dust killed all the termites present in these heavily infested poles.

window sashes were dead, but live termites were found in the end farthest from the treatment. A similar state of affairs was found in the treated floor boards, live dry-wood termites being numerous in the end of the boards which had not been treated. It was evident that more than one separate infestation was present in both the sash and floor boards. Two supports 6 inches x 6 inches x 12 feet (15 cm. x 15 cm. x 3.6 m.) infested with the dry-wood termite had a series of holes bored near the center of each, into which Paris green was injected. Fresh pellets continued to be thrown from the lower ends of these supports for two months after they were treated. Paris green was then blown into the holes from which the pellets were being ejected. The ejection of pellets ceased immediately and did not occur again during a three months' observation period. This incident proves the value of reinspection and retreatment in accomplishing complete control.

In field tests of *white arsenic* used as a poison dust treatment against infestation of the dry-wood termite, a commercial grade of the chemical was used. The product was a very coarse powder, probably not finer than 60 or 80 mesh per inch (24 or 32 mesh/cm.). Two 8-foot (2.4-m.) red cedar pole stubs infested with the dry-wood termite were treated. Half-inch (1.3-cm.) holes were bored into the infested wood at 3-foot (90-cm.) intervals and the white arsenic powder blown into them with a hand type duster. About 1 ounce (28 gm.) of powder per test stub, or, at 16 cents per pound, 1 cent's worth, was used for each treatment. These stubs were cut open for inspection 10 weeks after treatment. One showed all termites dead. In the other, although many termites had been killed by the white arsenic, many were still alive. The poor results with this material were blamed upon the coarseness of the dust.

Arsenical smelter dust is a very fine powder, the chief chemical constituent of which is white arsenic. It has been used extensively in commercial scale field tests on poles. The arsenical smelter dust, which was the most toxic dust poison studied in the laboratory, has given excellent results in the field. It is as effective as Paris green and much cheaper. The cost of the dust itself is small, the cost of application being the main factor.

Calomel, or mercurous chloride, was one of the materials first used in the early history of dust treatments for termite control. The Committee has made only one group of field tests with this material to study its effectiveness and cost. Two 10-foot (3-m.) pole sections infested with the dry-wood termite were treated, the calomel dust being injected into holes bored at 3-foot (90-cm.) intervals. Each piece required about 2 ounces (56 gm.) of calomel. As the retail price of calomel was $3.02 per pound, 38 cents' worth of dust was required to treat each 10-foot (3-m.) stub. These test pieces were cut open for inspection ten weeks after treatment. In each piece both live and dead termites were found, but the dead termites outnumbered the live ones, the kill being roughly estimated at 60 per cent. The poor results obtained and the relatively high cost of the material precluded further tests with calomel.

Laboratory tests showed *sodium fluosilicate* dust toxic to termites. This substance is usually considered non-poisonous to man and would be an ideal material for the control of termites in dwellings. Field tests of the sodium fluosilicate dust treatment were made on two 8-foot (2.4-m.) sections of poles infested with the dry-wood termite. Holes were bored in the infested timbers at 3-foot (90-cm.) intervals and the dust was injected with the hand type duster. The dust used was a commercial grade of sodium fluosilicate which is quite coarse, probably not finer than 80 mesh per inch (33 mesh/cm.). One and one-half ounces (42.5 gm.) of the dust were used to treat each 8-foot (2.4-m.) stub, or, at 20 cents per pound, 2 cents' worth of sodium fluosilicate. These test stubs were cut open and inspected ten weeks after treatment. In one, all the termites had been killed; in the other, one small group of the insects survived the treatment, the estimated kill being about 98 per cent.

Further commercial scale field experiments were made with finely ground sodium fluosilicate, all of which would pass a 200 mesh per inch (80 mesh/cm.) screen. Poles and wooden oil derricks infested with the dry-wood termite were treated. Where the wood was dry the treatments were successful, giving 100 per cent kill. Some difficulty was found in handling this dust in damp weather, as the powder showed a tendency to stick together. Treatments of damp-wood termites were not successful. Since sodium fluosilicate is somewhat soluble in water, the dust caked in the damp wood and was either avoided by the termites or lost its effectiveness. Where the wood treated was dry, the fine sodium fluosilicate powder was as effective for termite control as the poisonous arsenical dusts.

A commercial preparation, *Flu-si-dust,* the toxic ingredient of which is sodium fluosilicate, was tested on poles infested with the dry-wood termite. The grade tested contained 70 per cent sodium fluosilicate and 30 per cent diatomaceous earth, an inert ingredient, which was added to produce a lighter dust for easier handling and to overcome the caking of the sodium fluosilicate when used in damp wood. Tests showed this material to have no advantage over pure sodium fluosilicate. In fact, the *Flu-si-dust* treatments were not so effective as those with sodium fluosilicate, because the addition of an inert ingredient decreased its toxic power.

Commercial *barium fluosilicate* is an extremely fine white powder. Due to its low solubility in water, it was expected to show little tendency to cake when used in damp wood. Although laboratory tests showed its toxicity to termites to be very low, the mechanical advantages of this product warranted its trial on a field scale.

Experimental dust treatments with barium fluosilicate were applied with the hand type dust gun to poles infested with the dry-wood termite. The dust was injected into the infested poles through holes bored at 3-foot (90-cm.) intervals. Two months after treatment the poles were removed and inspected. In the dry poles, although the dust had killed some of the termites, great numbers of them were left unharmed. The results were not satisfactory. Where the wood of the pole was damp the barium fluosilicate dust showed a strong tendency to cake. After the dust had caked the treatment seemed worthless, and there was almost no killing of the insects in this case. Similar results were obtained from half a dozen test poles, all of which indicated clearly the failure of the barium fluosilicate to control the dry-wood termite.

Dust tests on damp-wood and subterranean termites.—Tests covering the use of poison dust treatments for the control of the damp-wood termite, *Zootermopsis angusticollis,* and the subterranean termite, *Reticulitermes hesperus,* were made under various conditions. Infested wood ranging from small blocks to large timbers were treated. The treatment was applied to damp wood and to dry wood, and to wood both on and in the ground. Where the test specimens were less than 3 feet (90 cm.) long, only one or two holes were bored into the infested wood for the injection of the poison. Larger specimens were treated every 3 feet (90 cm.). The wood in these tests was removed and inspected seven weeks after treatment.

In wood which was dry, dust treatments with Paris green, arsenical smelter dust, and sodium fluosilicate gave satisfactory control, particularly if the wood had been so damaged by the termites that it contained well defined runways and cavities, all of the insects in the infested wood having been killed. In the case of the subterranean termite a central nest from which many objects may be attacked is supposedly located elsewhere under ground, so that, obviously, one cannot expect to reach the nest through dry runways.

Infestations of the damp-wood termite could usually be handled with reasonable success by dust treatments with Paris green or arsenical smelter dust. If the wood is damp, but not actually wet, these dusts do not cake, and thus they retain their effectiveness. Sodium fluosilicate cakes in wood which is only slightly damp, and is therefore worthless in connection with the damp-wood termite.

Paris green and arsenical smelter dust showed some effect on the subterranean termite, except where the wood was very damp. Control was not complete, but the number of termites in the infestation was greatly diminished. In wood which was fairly wet some of the insects were killed, but it was evident that the galleries containing the poison dusts had been sealed away from the rest of the colony with dams of mud and wood particles. In very wet wood these dusts were found caked. Sodium fluosilicate was worthless in the damp wood against the subterranean termite. In general, the dust treatment was not considered satisfactory as a control measure for the subterranean termite.

Tests of Paris green dust against the subterranean termite, made by Dr. Smith at the Citrus Experiment Station at Riverside, California, showed excellent results. He informed us, however, that his tests were made during the summer, when the infested wood was very dry. In fact, his one failure to obtain control with Paris green was on an infested stake set 14 inches (35 cm.) in the ground, and was probably due to moisture.

Baits and dusts for remedial and palliative treatments.—Poison baits are said to have been used successfully in the tropics against the harvesting termite, which leaves its nest to forage for bits of straw and chaff. The bait is ordinarily bits of straw or chaff soaked in a solution of sugar and sodium arsenite.

In Australia a poisoned bait has been recommended for the extermination of termites damaging wooden structures. The bait is made by mixing 1 ounce

(28 gm.) of white arsenic, or, better, of sodium arsenite, with 1 pound (454 gm.) of treacle. The mixture is poured into any infested woodwork not to be removed in repair. Other investigators have found little success with poison baits. The baits were found to kill only a few insects, and their practicality for termite control was doubted.

Laboratory tests of baits were made by us on the dry-wood termite, the damp-wood termite, and the subterranean termite. Attempts to attract termites to cane sugar and sugar solutions were unsuccessful. Instead of searching for the sugar, the insects seemed to avoid it. Poison baits of 10 per cent white arsenic in honey and 0.5 per cent sodium arsenite in a dilute sugar solution were of no value. The termites could not be induced to taste them.

Conclusions on the use of baits and poison dusts.—(1) The introduction of poison dusts into the termite galleries is the most effective known remedial treatment for wood infested with the dry-wood termite. (2) The most effective poison dusts are Paris green, arsenical smelter dust, and finely ground sodium fluosilicate. Sodium fluosilicate has the advantage of being nonpoisonous to man, but is effective only if the infested wood is dry. (3) Paris green and arsenical smelter dust show some promise for the control of the damp-wood termite. (4) Satisfactory control of the subterranean termite cannot be obtained by poison dust treatments. This is particularly true where the infested wood on or in the ground is damp. (5) Poisoned sweet baits offer no solution to the control of the termite species of western North America.

II. THE TOXICITY OF VARIOUS POISONOUS DUSTS

BY

CHARLES A. KOFOID AND O. L. WILLIAMS

Poisonous dusts seem to be particularly adapted to the destruction of termite colonies already established in poles or wooden structures. The reasons for this are three: (1) Since the termite colony lives in a closed system of passageways, the movements of its individuals are necessarily limited; when a poisonous dust is introduced at any point in the system, retreat and escape are impossible. The result of this condition is that the movements of the individuals effect a rapid spreading of the dust throughout the system of runways. (2) Due to the small bore of many of the passageways there is crowding of the termites; through bodily contact, as well as through contact with the walls of the passageways, dusted individuals spread the poison to many others, each of which may, in turn, pass on a small amount of dust to still others. (3) During the grooming act a termite may clean off its own antennae, palps, or legs; it may very hurriedly snatch a few particles of dust from another individual as it runs by; or it may spend many seconds carefully cleaning that individual. In any case, it is likely that a lethal dose may be taken in very quickly if one of the more toxic dusts is used. Termites groom themselves and each other extensively, and in the spread and intake of poisonous dusts the habit of grooming must be considered of fundamental importance. The delicate sensory hairs on the antennae and legs of the termite are stimulated by contact with the particles of dust, and this induces and accelerates the grooming reaction (chap. 24).

Classification of poisons.—Poisonous dusts may be divided into two classes, namely, *contact poisons* and *stomach poisons*. Contact poisons kill or injure upon mere contact with the insects, while stomach poisons must be ingested to be of effect. Of the two classes, contact poisons are much the more rapid in their action, but experiments have shown that they are less effective for use as termiticides. The reasons for this fact are, first, the grooming habit, so important in the spread of dust through the colony, is reduced to a minimum if an irritating substance is used, and second, recovery from the effects of a contact poison is not uncommon, while recovery from a stomach poison rarely if ever occurs. In termite control work it is important that a highly toxic and non-irritating stomach poison be used.

Method of comparing toxic dusts.—In comparing the toxicity of various substances the time factor, or rate of killing, was used. A standard number of termites was subjected to the poison and the number dead after various lapses of time noted. Each test was continued until all of the termites were dead, excepting those cases in which the dust proved non-toxic. However, numerous investigators have shown, and we have found, that more accurate results can be obtained in determining the toxicity of a given substance if the comparisons of the killing powers of toxic substances are made with mortality percentages of less than 100. Therefore, in the present work the standard of comparison selected was the time required to kill 80 per cent of the termites. This method is particularly adapted to termite work, because it not only reduces errors accountable to individual variation in susceptibility to the poison, but it also reduces the much greater error caused by molting termites. These termites refuse to ingest the poison and live for long periods of time after the remainder of the colony has been killed. Such fasting insects are not really involved in the experiment, but it is not often possible to eliminate them in selecting the individuals for an experiment.

Method of testing.—In order that the toxicity tests might be standardized, a uniform method of procedure was selected. Each test was made in a Petri dish 9 cm. in diameter, the bottom of which was completely covered with a layer of moist filter paper. Fourteen nymphs of the species *Zootermopsis angusticollis* were then placed in the dish, and a fifteenth, having been thoroughly dusted with the toxic material to be tested, was added. The dusting process was carried out by placing the termite in a watch glass with 2 or 3 grams of the dust and shaking the glass about until no more dust would adhere to the termite. Observations as to rate of death were recorded at various intervals, depending largely upon the effectiveness of the dust.

A number of modifications of this procedure were used, all with equal success and comparable results. One extensive series of tests was made in which 1 dusted termite was placed with 24 undusted individuals. No important difference was found in the time required to kill all the termites in the dish when this larger number of insects was used. Even when still larger numbers of undusted individuals were used, the time required to kill the whole group was only slightly longer than when only 15 individuals were used. This was demonstrated by placing 1 dusted termite with 49, 99, and 249 undusted individuals, respectively. Therefore, for purposes of determining the comparative toxicities of dusts, experiments with only 15 termites were used.

In calculating the comparative toxicities of the dusts an arbitrary scale of toxicity was devised. The most toxic dust, "bag-house" or white arsenic, was considered, for purposes of comparison, 100 per cent toxic; those dusts which required a longer time to kill 15 termites naturally fell between zero and 100 per cent. Dusts which were ineffective after the test had continued for 1,000 hours were considered non-toxic, and all tests on such materials were discontinued at that time. One thousand hours was selected as the zero point in the toxicity scale.

In addition to *Zootermopsis angusticollis,* two other species of termites, *Reticulitermes hesperus* and *Kalotermes minor,* were used in a smaller series of tests. It was found that the results with these two species of termites were comparable with those in which *Z. angusticollis* was used, the killing time with the various dusts being slightly shorter, however, for both species of the smaller series.

Summary of results.—Table 38 summarizes the results obtained in the main series of tests in which *Zootermopsis angusticollis* was used. It will be noted that the list of twenty-three toxic dusts is arranged according to toxicity, starting with white arsenic. The time in hours required to kill 80 per cent of the fifteen termites in each test is also given.

TABLE 38

	Hours to kill 80 per cent
White arsenic	18
Sodium arsenite	24
Sodium fluosilicate	38
Sodium fluoride	39
Barium fluosilicate	48
Paris green	67
Barium arsenate	74
Cryolite	112
Potassium fluosilicate	120
Magnesium fluosilicate	125
Calcium fluosilicate	127
Barium chloride	130
Copper carbonate	138
Mercurous chloride	142
Borax	164
Strychnine	166
Zinc oxide	280
Sulfur	402
Sodium chlorate	448
Zinc acetate	460
Zinc sulfate	468
Boric acid	520
Zinc chloride	570

The following miscellaneous materials were found to be non-toxic to termites within the limits established above: aloes, aluminum ammonium sulfate, ammonium bichromate, ammonium bromide, ammonium carbonate, ammonium chloride, ammonium molybdate, ammonium nitrate, ammonium phosphate, ammonium sulfate, copper fluosilicate, oxalic acid, pyrogallic acid, sodium bisulfite, and tannic acid.

Conclusions.—The above table comparing the toxicities of twenty-three dusts shows clearly that arsenicals and fluosilicates are highly toxic to termites. The fact that certain of the fluosilicates, particularly those of sodium and of barium, are relatively non-toxic to man suggests the advisability of using them in dwellings or in situations where some more dangerous material should be avoided.

Methods of using toxic dusts in termite control work and accounts of field experiments are given on page 435.

CHAPTER 39

TREATMENT BY FUMIGATION

BY

MERLE RANDALL, THOMAS C. DOODY, AND BERNHARDT WEIDENBAUM

Fumigation has always been a popular method of controlling insect pests. Where fumigation treatments are successful large numbers of the insects can be taken care of in a single treatment. The pest can usually be controlled with a minimum of effort and inconvenience, and the wholesale killing of a pest, as by fumigation, meets with more favor than a tedious but effective control of it. It was natural that fumigation processes should be applied to the control of termite infestations. A few successful or apparently successful treatments soon led to the popularization of so simple a control measure.

At the time the Committee began to study the value of fumigation for termite control it was believed to be the most satisfactory remedial measure for ridding buildings of the dry-wood termite. Hydrogen cyanide was the fumigant usually recommended for this purpose. There were some striking successes in the use of hydrogen cyanide, but failures to obtain complete control of the insects occurred so often that fumigation was not advertised or widely acclaimed for termite control.

Fumigation for the control of termite infestations was studied rather completely by the Committee. We have been able to show that it is not the panacea for termite control. It is adaptable to some few special cases, which will be taken up in detail.

Fumigants can be used to reduce the number of insects in an infestation, thereby retarding the damage, but complete extermination is seldom accomplished. The results usually obtained are not considered worth the cost of treatment. Volatile fumigants used against subterranean termites are effective for only a short time. The only fumigating material found satisfactory for the subterranean termite is paradichlorobenzene. This material gives a heavy vapor objectionable to termites and lasts long enough to give protection of some permanence.

Fumigation of dry-wood termites with volatile fumigants greatly reduces their numbers but is rarely completely effective. Furthermore, these fumigants leave no protection against further infestations. The use of poison gases for fumigation is not effective in killing termites in large timbers, and is not suitable or effective for the treatment of houses. Chloropicrin gives the most satisfactory results. Small objects, such as lumber and furniture, infested with the dry-wood termite could no doubt be satisfactorily treated by fumigation with the more toxic fumigants. Orthodichlorobenzene gives satisfactory control of the dry-wood termite, but is expensive. The dry-wood termite is best controlled by the previously discussed dust treatment if the colony is established and has done considerable damage. In general, only superficial damage by this insect can be satisfactorily controlled by fumigation.

Studies of the use of fumigation treatments for controlling termites and the damage done by them were made as early as 1863 by A. de Quatrefages. The effects of nitric oxide, chlorine, and sulfur dioxide gases on termites were investigated. The experiments showed chlorine was the most effective of these gases. Laboratory colonies, in which the termites had built nest structures, were fumigated by chlorine gas with complete success. Chlorine gas fumigations were believed practical but the treatment was never used extensively. The corrosive nature of chlorine gas probably prevented practical use of the treatment.

Sulfur and arsenic fumes.—Sulfur dioxide, the fumes produced by burning sulfur, was used successfully for termite control in 1903 by A. Loir. The sulfur vapors were blown into the termite galleries at several points under pressure supplied by a hand pump. The treatment was reported as satisfactory.

An improvement on this treatment has been used very successfully with mound-building termites, which are often believed the cause of extensive economic damage which is actually due to another subterranean species. This was discussed in papers by Escherich (1911) and Mackie (1911). The improved process consists of blowing the mixed vapors of sulfur and arsenic, which are produced in a pressure-tight iron stove, into the mounds or nests of the termites with a stream of air from a hand pump. These fumes condense and deposit a poisonous material on the walls of the galleries and on the insects themselves. Mackie believes this material to be arsenious sulfide. The deposited poison does not act immediately, but within a few days kills all the termites in the nest and makes that nest forever uninhabitable by the insects. A heaping teaspoon of a mixture of one part of arsenic to three of sulfur was sufficient to treat the average mound nest.

The equipment for this treatment was manufactured and sold under the name of *Universal Ant Exterminator.* It consisted of a gas-tight poison chamber and a hand pump for blowing air through the chamber to carry the vapors into the insect galleries. Beneath the poison chamber, and integral with it, was a charcoal-burning stove for vaporizing the mixture of sulfur and arsenic.

The Committee made a piece of equipment of this type and tested it with the arsenic sulfur mixture. The design of this equipment was probably not so suitable as the commercial apparatus for the treatment, and many difficulties were encountered in its manipulation. It was difficult to maintain the white arsenic and sulfur (1:3) mixture at the proper temperature for the efficient production of fumes. With the roaster too cold no fumes were produced, and with it too hot the viscous liquid sulfur frothed and boiled into the fume exhaust. Also, the method was unpleasant and dangerous.

Pole sections infested with the dry-wood termite were treated with the sulfur arsenic fumes by blowing into the insect galleries through holes bored in the infested wood. Observations were made on the effectiveness of the treatment after ten weeks. Very little material deposited from the fumes was found condensed in the termite galleries, and it was impossible to tell which runways had received treatment by the fumes. The results of the treatment were surprisingly good, since even with the unsatisfactory equipment practically all termites in the infested wood had been killed.

Conclusion.—The injection of arsenic sulfur fumes into the galleries of wood-dwelling termites is doubtless a very effective treatment. The dangerous nature of the fumes and the difficulty of controlling them make this treatment unsafe for use in closed places, such as infested buildings. The galleries of the subterranean termites of the Pacific Coast, which extend through the soil, are not large enough or well enough defined to allow the use of this treatment.

TESTS OF FUMIGATION TREATMENTS

Reports of fumigations for termite control showed both striking successes and failures. A study of fumigating processes was planned to determine the effectiveness, the possibilities, and the practicability of fumigation. The plan of investigation was (1) to study the toxicities of various fumigants, (2) to observe the method and the thoroughness with which these materials penetrated the termite galleries, and (3) to test the effectiveness of fumigating processes under field conditions.

Toxicity of fumigants.—The laboratory study of the toxicity of fumigants was made with the species *Zootermopsis angusticollis,* the damp-wood termite. This termite is easily kept and handled in the laboratory and was chosen as the standard test animal.

Our method of test was adopted because of its simplicity, and the results obtained are believed to be as accurate and indicative as those obtained by more complicated procedures. Tests were made at several concentrations of the fumigant vapors up to vapor saturation in most cases. The materials tested were carbon bisulfide, carbon tetrachloride, benzene, chloropicrin, and hydrogen cyanide.

All these chemicals are volatile liquids. The carbon bisulfide, carbon tetrachloride, and benzene were pure chemicals, and the chloropicrin and hydrogen cyanide were commercial products with a guaranteed purity of 97 per cent. The gas concentration of the fumigant was measured directly by careful weighing of the bottle, of known volume, in which the test was made, before and after the desired quantity of the liquid fumigant was added. The concentration figures were accurate to 1 milligram per liter. Some error in concentration was due to a small loss of gas by diffusion while transferring the termites to the gas-filled bottle. This loss was made as small as possible by adopting a rapid routine procedure for transfer. With a little practice the termites could be dumped from a vial into the test bottle and the bottle restoppered in less than one second. The loss of gas was small and approximately constant. The bottles containing the weighed amount of liquid fumigant were allowed to stand several minutes to insure complete evaporation of the liquid. During this period the bottles were shaken and their position changed often to insure an even concentration of the gas throughout.

Five full grown *Zootermopsis* nymphs were used in each fumigation test. This seemed the maximum number on which accurate observations could be made when the fumigant acted rapidly. The time required for complete anesthesia of the termites was determined by the cessation of motion of the antennae, since the motion of the antennae persisted longest. Often this was found not to be the time required for the fumigant to cause death. To check this, after apparent complete anesthesia, the termites were removed from the fumigant and placed in the open air. Termites from tests of some of the materials (carbon bisulfide and hydrogen cyanide) showed complete recovery

TABLE 39

DATA ON FUMIGANT TOXICITY TESTS

	Concentration gr./liter	Time in hours	1/time	No. of insects recovered
Carbon bisulfide	1.291	0.0085	118.0	0
	0.816	0.166	6.0	....
	0.236	0.666	1.5	5
	0.1261	1.25	0.817	4
	0.0627	6.0	0.167	4
Carbon tetrachloride	0.768	0.0375	26.7	0
	0.752	0.2205	4.54	....
	0.490	1.25	0.80	2
	0.319	1.50	0.666	2
	0.0024	5.84	0.172	5 alive, but affected
Benzene	0.333	0.0167	60.0	1
	0.302	0.15	6.66	....
	0.2785	0.233	4.28	1
	0.258	0.25	4.0	....
	0.160	4.75	0.211	....
Chloropicrin	0.3744	0.0667	14.99	0
	0.2040	0.1333	7.50	0
	0.1392	0.15	6.66	0
	0.1272	0.20	5.00	0
	0.0672	0.25	4.00	0
	0.0264	0.483	2.07	0
	0.0081	0.766	1.35	0
Hydrogen cyanide	0.0418	0.0175	47.1	0
	0.0352	0.0262	38.3	0
	0.0100	0.0485	22.48	2
	0.0054	0.0697	14.4	5
	0.0014	0.070	12.63	5
Turpentine (saturated vapor)	0.0327	31.0	....	0
Paradichlorobenzene (saturated vapor, solid present)	....	72.0	....	....
Naphthalene (saturated vapor, solid present)	....	96.0	....	....

in the lower concentrations. With other substances, notably carbon tetrachloride and benzene, although some of the insects recovered, under four or five days' observation they still showed the damaging effect of the treatment, usually as a partial paralysis. All of these fumigation tests were run at room temperature, about 22°C. Records of the relative humidity during this work showed a variation of 62 to 85 per cent, which sometimes occurred during the progress of one set of experiments.

The data on the tests with several fumigants are given in Table 39.

The data in the above table are plotted in the accompanying curves (fig. 130) to show the relative effectiveness of the fumigants studied. In the curves

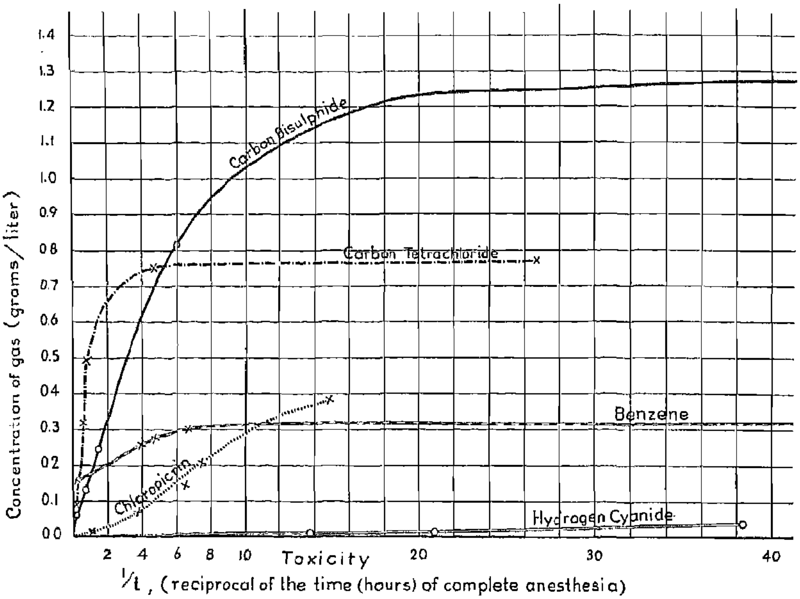

Fig. 130. Toxicity of benzene, carbon bisulfide, carbon tetrachloride, chloropicrin, and hydrogen cyanide to the damp-wood termite, *Zootermopsis angusticollis.* (0.01602 grams per cubic centimeter are equivalent to one pound per cubic foot.)

the concentration of chemical is plotted as ordinates and the reciprocal of the time is plotted as abscissae. The toxicity of any substance is inversely proportional to the time required for the material to kill; consequently, toxicity as here considered is the reciprocal of the time of kill.

It is interesting to note the rapid increase in toxicity as the concentration of each of the gases nears the vapor saturation point. It is evident from the curves of benzene, carbon tetrachloride, and carbon bisulfide that the change in their relative values as fumigants, with change in concentration, is due to this factor. The point of highest concentration for chloropicrin is above the vapor saturation point as given in the literature.

Conclusions.—(1) From the toxicities of the substances investigated we find hydrogen cyanide, chloropicrin, and benzene, in the order named, to be most effective; carbon tetrachloride and carbon bisulfide are less effective. (2) There is considerable change in relative toxic power with change in concentration. This change seems due to the rapid increase of toxicity near the vapor saturation point. (3) Data are included in the table on the toxic effects of saturated vapors of turpentine, paradichlorobenzene, and naphthalene. These materials do not compare very favorably in toxic power with the more volatile fumigants.

Method of testing diffusion of fumigants through termite galleries.—The manner in which termites damage wood, leaving spaces and galleries in the structure of the wood, led to the belief that fumigation processes would be effective for exterminating the termites. Sections of wood traversed by termite galleries were sealed with glass plates and paraffin at every point on the surface of the wood where the galleries had been cut or broken, so as to make each test block a closed chamber of termite galleries. Glass entrance and exit tubes by which the gas was led through the chamber were also sealed in with paraffin. In several cases it was found that the galleries throughout the small test blocks were not connected, and it was difficult to obtain passage of the gas through the block.

Moist chlorine gas was introduced into the galleries of one of these test blocks for twenty or thirty minutes. The block was then split and the path of the chlorine traced with an indicator, which showed that the chlorine had penetrated throughout the wood structure. Chlorine is known to react readily with the lignin of wood, and through this reaction appears to permeate the entire structure. Trials with sulfur dioxide showed that it, too, permeated the entire structure of the wood.

Nitrogen tetroxide (N_2O_4 and NO_2), prepared by the action of concentrated nitric acid on copper, was used for tracing the path of a gas through the termite workings. The nitrogen tetroxide stained the wood directly with a permanent and easily discernible yellow or brown color.

These tests were run on test blocks of western red cedar which were honeycombed with the galleries of the dry-wood termite. The nitrogen tetroxide was produced by the generator at a pressure of 1½ to 2 pounds per square inch (0.1 kg./sq. cm. above the atmosphere) and was passed through the test block for 25 to 30 minutes. The exhaust and inlet tubes were then sealed and the block left over night to allow time for the gas to diffuse through the galleries. The block was split for inspection and the stain showed that the gas had not diffused through all the galleries to which it had access. Two typical cases of this were noted.

One section showed the dead end of a chamber which was connected through a constricted passageway to a larger chamber in which the gas had been present. The gas had diffused through this passage, but the stain in the small, closed chamber was very light. The large chamber was sealed off from another chamber by a plug of the cement-like material composed of masticated wood or fecal matter with a gluey binder, which the dry-wood termite uses for this purpose. This plug proved to be gas-tight and there was no sign of stain from the gas in the sealed chamber. Another section showed a large closed cavity connected by a single very narrow tunnel to another large cavity in which the gas had been present. The diffusion through the small tunnel had not been rapid enough to show any stain of the gas on the walls of the large dead air chamber.

Conclusions.—(1) A transient gaseous fumigant diffuses into the dead air spaces in the termite galleries very slowly and probably does not reach all the termites in the infested wood. This is borne out by observations from field fumigation tests, the termites in fumigated logs being often found crowded to the ends of the blind galleries for safety.

(2) A fumigant which permeates the wood readily, or which reacts with it, would be more likely to kill all of the termites in infested wood than an inert fumigant. This will be further discussed under fumigation tests on hydrogen cyanide and chloropicrin.

Field fumigation tests and records.—The final step in the investigation of fumigation processes for the control of termites was to link the information obtained in the laboratory with the records of field work, and to perform field tests to judge the practicability of fumigation. Field tests with several volatile liquids and solids were performed on both subterranean and dry-wood termites. True fumigation processes, where the infested material is placed in the toxic gas, were tried on a field scale only with hydrogen cyanide and chloropicrin. These two substances were shown in our laboratory toxicity tests to be the most poisonous fumigants tested.

Hydrogen cyanide.—Hydrogen cyanide was the gaseous fumigant most often recommended for termite control. Many fumigation treatments of infestations by wood-dwelling termites were done with hydrogen cyanide (also known as HCN, hydrocyanic acid, and "cyanide"). It is an extremely dangerous material and should be used with great care, as suggested by Snyder (1916).

Hydrogen cyanide and subterranean termites.—Although hydrogen cyanide gas must have been tested extensively for control of subterranean termites, few definite records of its use have come to our attention. The opinion of Dr. T. E. Snyder of the Bureau of Entomology, U. S. Department of Agriculture, is that fumigation is of no permanent value against subterranean termites in buildings. Hydrogen cyanide, a gas slightly lighter than air, cannot be expected to settle into the soil or to remain there, so as to exterminate groups or nests of subterranean termites. Although no test of this was made, the Committee collected all available information on the subject of fumigation of termites with hydrogen cyanide and presents the following instances.

A one-story frame house at Azusa, California, was subjected to fumigation for control of the subterranean termite. At that time the house was about twenty-five years old. It was so badly damaged by the subterranean termite that considerable replacement of woodwork at the front porch and the adjoining portion of the house was necessary. The owner procured two large canvas tents of the type ordinarily used for citrus tree fumigation and covered the house with them. One tent would not have covered the house completely, so two were used, overlapping to a considerable extent. A very heavy dosage of hydrogen cyanide was used, although the exact concentration is not known. The ordinary dosage for citrus tree fumigation is 18 cc. of liquid hydrogen cyanide per 100 cubic feet (2.8 cu. m.), which is approximately 0.4 per cent hydrogen cyanide by volume. The amount of hydrogen cyanide used in this fumigation was roughly ten times that used on citrus trees and the exposure time was 5 or 6 hours. After fumigation the carpenters tore down the front porch and a portion of the front of the house to determine its effect. All termites near the surface of the wood and in galleries up to about 2 inches (5 cm.) from an outside opening were killed. The termites inside larger pieces of wood, or in galleries more than 2 inches (5 cm.) from an outside opening, even though their actual position was not more than ½ inch (1.3 cm.) from the surface, were alive and active as if nothing had occurred to disturb them.

We also examined several contract jobs done by a San Francisco company, specializing in cyanide fumigation work, for controlling infestations of the subterranean termite. The hydrogen cyanide used by them is generated from sodium cyanide and sulfuric acid. The dosage used is 10 to 30 ounces of sodium cyanide per 1,000 cubic feet (10 to 30 gm./cu. m.) (known as 100 and 300 per cent dosages, respectively), or approximately 0.4 per cent to 1.2 per cent of hydrogen cyanide gas by volume. The period of fumigation is about 24 hours. A second treatment is always given 10 days after the first.

This company treated a record vault for the Southern Pacific Company at Empalme, Mexico, in which considerable damage was being done by *Heterotermes*, a subterranean termite. The treatment appeared satisfactory, as complete control of the termites was reported by both companies. About six months later these vaults were inspected by a member of the Termite Investigations Committee. Termites were found coming through cracks in the floor of the vault and attacking the records there. Although the cyanide fumigation had killed the termites in the vault at the time of treatment, it was not effective in controlling the infestation.

An infestation of the subterranean termite in the basement of a San Francisco hotel was treated by the same company. Great difficulty was reported in obtaining complete eradication of the termites there and the fumigation had to be repeated several times. Up to six months after the last treatment no recurrence of the insects had been reported.

The fundamental principle in the plan for control of subterranean termites by the use of hydrocyanic acid fumigation is unsound. The process cannot be expected to give complete and permanent eradication of the termites.

Hydrogen cyanide and dry-wood termites.—The use of hydrogen cyanide gas fumigation for the extermination of the wood-dwelling types of termite, where the entire life of the colony is in the wood without outside connections, appeared more practical. It has been recommended and used more widely for dry-wood than for subterranean termites. In *Farmer's Bulletin 1472* of the U. S. Department of Agriculture (Snyder, 1926*b*) successful cyanide fumigations of wood-dwelling termites are reported. The cyanide concentration recommended is 20 per cent stronger than that ordinarily used for household insects, or 12 ounces of sodium cyanide per 1,000 cubic feet (12 gm./cu. m.)

to be fumigated. The usual proportions, 1 ounce (avoirdupois) (28 gm.) of sodium cyanide, 1½ fluid ounces (44 ml.) of sulfuric acid, and 3 fluid ounces (89 ml.) of water (Snyder, 1916) are used in the generators. The recommended concentration is about 0.5 per cent of hydrogen cyanide gas by volume, instead of the normal 0.4 per cent obtained at 10 ounces of sodium cyanide per 1,000 cubic feet (10 gm./cu. m.). Details of one of these successful treatments were kindly furnished us by Dr. Snyder (1916) of the Bureau of Entomology, U. S. Department of Agriculture.

A Florida hotel was badly infested with the dry-wood termite, *Cryptotermes brevis*. The damage was found to be most severe in the woodwork and furniture of the third, fourth, fifth, and sixth floors. The doors and windows were sealed, and the hotel fumigated with the recommended 120 per cent dosage of hydrogen cyanide. The period of fumigation was 2½ days, at the end of which time a "liberal amount" of the gas was said still to be present. At the time of inspection furniture and doors were cut into and many dead nymphs and winged forms were found. The treatment was judged to be thoroughly satisfactory.

Reports of trials in 1928 of cyanide fumigation on poles infested with the dry-wood termite also came to our attention. A pile of infested poles was covered and sealed as tightly as possible with four thicknesses of canvas. Four times the concentration recommended for household insects, *i. e.*, a 400 per cent dosage of hydrogen cyanide, was used. The period of fumigation was 40 hours. Inspection showed that the termites in the galleries near the pole surfaces, the winged forms in particular, had been killed. Many live nymphs were found to be unaffected.

Recent trials at control of the dry-wood termite in infested lumber of 1 and 2 inch (2.5 and 5 cm.) thicknesses have proved the effectiveness of cyanide fumigation. Infested lumber piles were covered tightly with canvas and fumigated with about a 200 per cent dosage of hydrogen cyanide. This treatment gave complete kill of the termites in the infested lumber. To facilitate the action of the treatment the lumber was so piled that many spaces for diffusion of the gas were left and the fumigation was allowed to run 48 hours.

This contradictory evidence on a treatment which appeared so practicable and promised to become popular led to a thorough semi-field investigation by the Committee.

Test No. 1.—Eleven sections of telephone poles, mostly western red cedar, infested with the dry-wood termite, were used in this test. The pieces were from 8 to 12 inches (20 to 30 cm.) in diameter, and from 3 to 15 feet (1 to 5 meters) in length, and were prepared as follows:

The surfaces of three pieces were chipped off and the galleries at the cut ends left open. This was to allow free access of the gas to the termite galleries. There were two pieces with open galleries at the cut ends; three pole tops with the galleries in the cut end sealed up with paraffin, and three pieces with the galleries which had been cut open at each end sealed up with paraffin. The test specimens were fumigated in a tile chamber of 3,000 cubic feet (84 cu. m.) capacity. The dosage of hydrogen cyanide used was 17 fluid ounces of liquid hydrogen cyanide per 1,000 cubic feet (17 gm./cu. m.), *i. e.*, a 300 per cent dosage, or about 1.2 per cent of hydrogen cyanide gas by volume. The fumigation period was 24 hours and the temperature during that time ranged from 21°C. to 24°C. The gas was still strong in the chamber after the 24-hour fumigation. The pole sections were then placed in the open air for 24 hours so that any termites which were anesthetized but not killed might recover.

A detailed inspection of the test specimens showed that the cyanide treatment was not completely effective. All termites in the wood within 1 inch (2.5 cm.) of the surfaces exposed to the gas, within 1 inch (2.5 cm.) of weather checks or breaks in the pole, and in wood that was so damaged by termite attack as to be extremely porous, were killed. The average penetration of the gas along the end grain of the wood was about 10 inches (25 cm.). A large proportion of the termites, those in the heartwood and in the sounder parts of the poles, survived the treatment without evident damage. This was true of both nymphs and winged forms.

This test was extensive enough to include typical workings of the dry-wood termite such as might be expected in actual field conditions. The failure of the gas to give a 100 per cent kill was general throughout all of the test pieces. The process of fumigating infestations of the dry-wood termite with hydrogen cyanide is therefore believed to be worthless for large timbers. Fumigation in an air-tight chamber with a 300 per cent hydrogen cyanide dosage gave this experiment every chance for success, above what might be expected in actual field conditions.

One possibility of the treatment had been overlooked. The fumigation process might have affected the intestinal fauna of the termites. Termites are known to die, apparently from starvation, when their intestinal Protozoa have been killed. Therefore the fumigation experiment was repeated (test No. 2). This time the wood was left several days after the fumigation before it was inspected, so any possible after-effects of the treatment would become evident.

Test No. 2.—A small group of western red cedar pole tops and eucalyptus stumps infested with the dry-wood termite were fumigated with hydrogen cyanide in the same chamber and under the same conditions as in test No. 1. The material from this test was divided into two groups. One group was kept in the open air for 10 days before inspection. A small 2-foot (60 cm.) section of a red cedar pole top showed 100 per cent kill, but a section of eucalyptus stump, in which the wood was quite solid, was estimated to have only 60 per cent of the insects killed. The remaining insects appeared normal and healthy, showing no effects from the fumigation. If the intestinal fauna had been killed, the appearance of the termites 10 days after fumigation would have given some indication of it.

The second group of specimens in this test were put in tight metal cans immediately upon being removed from the fumigation chamber, and were shipped to the laboratory for investigation. The cans were opened and the material inspected 5 days after treatment. The wood still retained a faint odor of hydrogen cyanide. All termites had been killed. The wood, however, had been severely damaged by the insects and would be classified as porous.

The effect of hydrogen cyanide on the intestinal Protozoa of the damp-wood termite was also checked in the laboratory. The intestinal Protozoa of *Zootermopsis* which had been fumigated with hydrogen cyanide gas and were then given 24 hours to recover, were investigated under a microscope. The fauna was found to be almost normal.

Test No. 3.—A third lot of material was fumigated with hydrogen cyanide under the same conditions. After the 24-hour fumigation period the material was removed from the chamber and stored in the sheltered corner of a small shed for 5 days before inspection. The wood still had a faint odor of hydrogen cyanide at the time of inspection. This test group of material, infested by *Kalotermes minor*, included some recently infested lumber in 1 and 2 inch (2.5 and 5 cm.) thicknesses. Inspection showed a complete kill of all the termites by the hydrogen cyanide gas.

Conclusions from tests.—(1) Timber infested with the dry-wood termite may be effectively fumigated in 24 hours with hydrogen cyanide at a 300 per cent dosage, about 1.2 per cent of hydrogen cyanide gas by volume, when

(a) the timber is so badly damaged by termite attack that it is porous;
(b) the termites are within 1 inch (2.5 cm.) of the pole surface, or of any break or check to which the gas has access.

(2) The termites in galleries in sound wood are not killed by a 24-hour exposure to hydrogen cyanide fumigation.

(3) The surviving termites show no after-effects of the fumigation treatment.

(4) The intestinal Protozoa of the termites are not destroyed by the fumigation.

(5) When wood is kept in a sheltered or enclosed space after fumigation the effectiveness of the treatment is increased. A longer exposure to the hydrogen cyanide, even at a much smaller concentration, increases its efficiency in reaching the termites in the galleries in sound wood. This is probably due to the absorption of hydrogen cyanide and its permeation of the wood structure. Absorption of the gas is indicated, since every particle of the wood stored after fumigation gave a faint odor of hydrogen cyanide.

(6) The results indicate that hydrogen cyanide fumigation would be satisfactory for the control of termites in furniture, small timbers, and lumber which had recently been infested. In fact, where the insects could not be more than 1 inch (2.5 cm.) from the surface exposed to the hydrogen cyanide, the gas should be quite effective.

(7) Fumigation gives no protection against future infestation.

Vacuum fumigation.—Many materials treated with hydrogen cyanide gas are put through a vacuum fumigation process. The materials to be fumigated are sealed in a steel cylinder and air is evacuated as completely as possible. Hydrogen cyanide vapor is then run in and the fumigation is allowed to proceed the desired length of time.

Vacuum fumigation with hydrogen cyanide was not investigated by the Committee because it was not applicable to the treatment of houses and other structures which furnish the greatest demand for a fumigation treatment.

Termite-infested objects such as furniture, lumber, etc., small enough to be treated in a fumigating retort could be satisfactorily treated by this method. Diffusion of the cyanide gas through the evacuated termite galleries would be expected to be rapid, thorough, and effective. The vacuum fumigation treatment would be suitable, also, for the sterilization of imported goods which may be termite-infested. Before the treatment is used extensively information should be obtained on the amount of hydrogen cyanide and the time of exposure required for thorough fumigation.

Chloropicrin.—This was one of the gases used during the World War and was known as "vomiting gas." It was used extensively both as a lachrymator, or tear gas, and as a lethal gas. It is a stable liquid, boiling at 112°C., and having a vapor pressure of 18.2 mm. of mercury at 20°C. The material is relatively safe to handle for fumigation purposes, because its action as a tear gas at very low concentrations gives warning of its presence in amounts too small to be dangerous.

The use of chloropicrin as an insecticide, emulsified with soap and water, was first proposed as early as 1907 (Halworth, English patent 20,387). Its insecticidal properties were first investigated about 1917, and it is now finding extensive use as a fumigant, particularly for stored products. In our laboratory tests of the toxicity of fumigating materials, chloropicrin proved, next to hydrogen cyanide, to be the most toxic of the materials studied. Considerable study has also been made in France of chloropicrin for termite control.

Chloropicrin and subterranean termites.—Chloropicrin gives a vapor 5.7 times as heavy as air, which makes it suitable for the treatment of soil-dwelling insects. It has, in fact, been used with great success in this connection. Chloropicrin for soil treatments has been used both as the pure liquid and dissolved in water. It is very slightly soluble in water, about one part in a thousand at 20°C. Due to its high toxic power, it should be satisfactory if used copiously on the soil in this high dilution.

The use of chloropicrin as a soil treatment for subterranean termites appeared very promising and the Committee planned a cooperative field test of its value. At the time the only available places for experiment were occupied houses, the basements of which were infested. A study of the literature showed that even in the open chloropicrin was persistent enough to be dangerous after five or six hours. Other experimenters included warnings that, due to the heaviness of the chloropicrin vapor, it was only removed from closed spaces slowly and with difficulty by airing. For these reasons the project was dropped.

In France chloropicrin has been tested for the control of wood-destroying termites by Feytaud (1920). His work was with the European subterranean termite, *Leucotermes lucifugus* Rossi, which he attempted to destroy in the wood instead of in the soil. In the laboratory he studied the effect of chloropicrin vapor on termites by fumigating blocks of termite-infested wood. His observations on the effect of the gas show that the insects exposed become excited and confused, then paralysis follows, and finally complete anesthesia. He remarks that the insects which have been paralyzed by the gas never recover from its effects. Termites even in the interior of blocks of wood 2½ inches (6.3 cm.) thick were killed. For positive results Feytaud recommends a minimum concentration of 10 mg. per liter for a 12-hour period.

The first floor of a building damaged by termites was fumigated by Feytaud with chloropicrin at a concentration of 16 grams per cubic meter, or about 1 pound per 1,000 cubic feet. All doors and windows were sealed and part of the floors and woodwork removed to allow free access of the gas. A 16-hour fumigation period gave complete success, even killing the termites in the beams.

Later work by Feytaud (1925) has shown that successful fumigations with chloropicrin can be carried out more easily by installing panels of wood particularly susceptible to termite damage several months before the treatment, to localize the termite infestation. This localization of damage is said to leave no isolated parts of the colony after treatment, such as heretofore had remained a potential menace to the building.

Chloropicrin and dry-wood termites.—No record was found of the use of chloropicrin for the fumigation and control of infestations of the wood-dwelling termites. A comparison of chloropicrin with hydrogen cyanide for this purpose seemed desirable, and small scale fumigation tests of infested wood were arranged by the Committee. Two chloropicrin fumigation tests were made in a small gas-tight fumigation chamber. The required amount of liquid chloropicrin was placed in the fumigation chamber with the infested material, where the gas distributed itself by diffusion. The exposures to the fumigant were for a 24-hour period.

Test No. 1.—Two pole sections 9 inches (23 cm.) in diameter and 2 feet (60 cm.) long, infested with the dry-wood termite, were used in this test. One pole section was badly split, and had considerable of the surface of the pole chipped off where there were termite galleries in the sapwood; the other test specimen was of comparatively sound wood. The fumigation was carried on at a concentration of 1 pound of chloropicrin per 1,000 cubic feet (16 gm./cu. m.). The temperature during the 24-hour fumigation period ranged from 37°C. to 21°C. After fumigation the wood was aired for 24 hours before inspection to allow for recovery of any insects stupefied by the fumigant.

There was 100 per cent kill of the termites in the test piece whose wood was not sound. In the sound test specimen both living and dead termites were found. The live termites showed no effect of the treatment at that time. Three groups of termites were collected from this pole and kept in vials for future study. One group consisted of apparently dead termites only; the second, of both live and dead termites taken from the same chamber in the same gallery, just as they were found; and the third group, of live termites only which showed no effect of the treatment.

The apparently dead termites showed no sign of recovery. A faint odor of chloropicrin remained in the vial for several days, although it was not noticeable when the insects were first collected. The live termites in the group of living and apparently dead termites died within 36 hours of the time they were collected. Here, again, the odor of chloropicrin could be detected in the vial.

The group of live termites died within 4 days after their collection from the fumigated wood. It was first thought this might have been due to unfavorable conditions in transporting specimens in sealed vials. The situation was confirmed, however, by the death of a similar group retained in the laboratory at which the fumigation was performed, the death of these termites having occurred in about the same number of days after the treatment.

These results indicate that the termites absorbed some of the chloropicrin through their breathing tubes and body covering. A study by Moore and Graham (1918) of the effects of chloropicrin on cockroaches had already indicated this. The sustained action of the absorbed chloropicrin is effective in killing the termites which have been subjected to the vapor.

Test No. 2.—Two more pole sections infested with dry-wood termites were fumigated in the same chamber at a concentration of 2 pounds of chloropicrin per 1,000 cubic feet (32 gm./cu. m.), twice the concentration used in the former experiment. The fumigation period was 24 hours, at an average temperature of 23°C. Inspection after treatment showed that one of the test pieces was badly damaged by termites, that most of the damage to the other specimen was in the sapwood, and that all of the termites had been killed, even those in small galleries in the sound wood most remote from the surface of the pole.

Conclusions from tests.—The tests with chloropicrin show it to be more effective than hydrogen cyanide in destroying infestations of the dry-wood termite. This at first seems peculiar, as the laboratory tests show that hydrogen cyanide is several times more toxic than chloropicrin at the concentrations used. The slight difference in the concentrations used, 1 pound per 1,000 cubic feet (16 gm./cu. m.) for chloropicrin, and 0.8 pounds per 1,000 cubic feet (13 gm./cu. m.) for hydrogen cyanide, hardly seems sufficient to account for the greater effectiveness of the chloropicrin.

The termites exposed to chloropicrin show no recovery, while those exposed to small concentrations of hydrogen cyanide show complete recovery. Chloropicrin is more suited than hydrogen cyanide to a rapid fumigating process for termites in wood because of the greater solubility of chloropicrin in the wood fiber. As pointed out in the study of the mechanics of fumigation processes, fumigants which are soluble in the wood fiber and permeate the wood structure can be expected to be more effective than those which do not. Hydrogen cyanide also shows this effect of the permeation of the wood fiber but it occurs much more slowly. This accounts for the greater success of hydrogen cyanide in the longer fumigation periods.

Fumigating liquids.—Several materials which were used or applied as liquids, but whose effect was by fumigation, were studied for termite control. These were carbon bisulfide, carbon tetrachloride, benzol, and orthodichlorobenzene.

Carbon bisulfide and subterranean termites.—Carbon bisulfide and a carbon bisulfide emulsion are recommended by Snyder (1926*b*) for the treatment of soil-nesting termites where the soil is loose and penetrable by the vapors. Carbon bisulfide is a much used insecticide, the vapor being very toxic. In high concentrations it is dangerous to man, but the unpleasant odor of the material reduces the chance of harm from its use. The vapor is inflammable, however, and it should not be used where there is any danger of a flame being present which may cause an explosion. The vapor of carbon bisulfide, two and one-half times heavier than air, is suited for soil treatments.

Escherich in his book *Termitenleben auf Ceylon* (1911) tells of the successful use of carbon bisulfide for treating termite nests of the mound type. The liquid carbon bisulfide was poured in at the top of the nest and the heavy vapors settled throughout the structure. Although the treatment was effective, after the gas had gone no permanent protection remained to prevent rehabitation of the nest.

Extensive use of carbon bisulfide was made for the treatment of poles infested with the subterranean termite, *Coptotermes formosanus*, in Hawaii. The Joint Pole Committee of Honolulu treated 8,400 poles by pouring 8 ounces (22.6 gm.) of carbon bisulfide at the butt of each pole. The average cost of this treatment was 20 cents per pole. Immediate results indicated the eradication of the termites in the soil. A re-inspection less than six months after treatment showed a large number of poles re-infested. Although the material seems effective, it has no permanent value. This point seems quite definitely established in such an extensive experiment.

The Committee applied carbon bisulfide treatment to two poles in a test line infested with the subterranean termite, *Reticulitermes hesperus*. One of these poles was treated with ½ gallon (1.9 l.) of carbon bisulfide poured into two holes 1 foot (30 cm.) deep bored in the soil down the sides of the pole; the other was treated with 1 gallon (3.8 l.) of carbon bisulfide poured into a trench 1 foot (30 cm.) deep dug around the base of the pole. The treatments were covered quickly with well-packed soil to prevent loss of the material by evaporation. These poles were removed and inspected six months and ten months, respectively, after treatment. Live *Reticulitermes* were found in the butt of each pole. This confirmed other work showing that carbon bisulfide treatments have no permanence.

Carbon bisulfide has been used alone and in many mixtures for the so-called gassing treatments used by termite control operators. These treatments have been applied to wood and on dirt fills difficult to treat by other methods. They are not recommended, because the temporary and local extermination of the termites gives a false feeling of security, and proper repair and removal of the fundamental causes of the damage are consequently neglected.

Carbon bisulfide and dry-wood termites.—Experiments were planned by us to test the efficacy of the injection of liquid fumigants into the galleries of the dry-wood termite. The toxicity of carbon bisulfide vapor being well recognized, it was used more extensively with this species. Various methods of injecting the liquid into the termite galleries were tested.

Injection of the liquid carbon bisulfide at only one point was tried on pole sections infested with the dry-wood termite. A hole 14 inches (35 cm.) deep was bored into the top end of each piece and the liquid carbon bisulfide injected under a pressure of 50 pounds per square inch (3.5 kg./sq. cm.). The hole was sealed after treatment to prevent loss of the fumigant. One pole accepted 1 quart (0.95 l.) of the liquid, the other 2 quarts (1.9 l.) Ten weeks after treatment live termites were found in the poles. Those in the top of the poles near the treatment were dead. Live insects were left in increasing numbers toward the bottom of the poles and in the sapwood where the treatment had not reached them.

The next method tried was to treat the galleries in the sapwood only. A 12-foot (3.6 m.) section of pole infested with the dry-wood termite was used. Twelve holes 2 to 3 inches (5 to 8 cm.) deep were bored into the pole surface. Carbon bisulfide liquid was injected into each hole under 50 pounds (3.5 kg/sq. cm.) pressure and the holes sealed. Ten weeks later live termites remained in some parts of the sapwood and in the galleries in the heartwood.

Two other infested poles, about 12 inches (30 cm.) in diameter, were treated every 3 feet (90 cm.) by boring a hole 7 inches (17.5 cm.) deep and injecting the liquid carbon bisulfide. Each hole was bored at an angle of 120 degrees to the neighboring one, and all were sealed after treatment. It took about a gallon (3.8 l.) of the liquid to treat each 12-foot (3.6 m.) section. The poles were cut up for inspection ten weeks after treatment. All the termites in one had been killed by the carbon bisulfide vapor. One small colony of live insects was found in the sapwood of the other test piece. None of the carbon bisulfide remained in these test poles at the time of inspection.

These tests showed that for greatest effectiveness liquid fumigants must be injected deep into the infested wood. Surface injections should be made not more than 3 feet (90 cm.) apart. Although this type of treatment diminishes the number of termites, it is not completely effective. Since the treatment is not permanent, any small groups of termites which may not have been killed will persist when the vapors of the fumigant have gone.

Carbon tetrachloride, another liquid fumigant, is less toxic than carbon bisulfide at low concentrations. Near its vapor saturation point, however, it is more effective than the same quantity of carbon bisulfide. Its vapor is more than five times as heavy as air. The great advantage of carbon tetrachloride lies in the non-inflammability of its vapor. It has been recommended for the fumigation of termite-infested soils by Snyder (1926*b*).

The effects of carbon tetrachloride on the subterranean termite was studied by treating two infested poles. One was treated by boring two holes in the earth down the sides of the pole and pouring a quart (0.95 l.) of carbon tetrachloride in each. A trench about a foot (30 cm.) deep was dug around the butt of the other pole and ½ gallon (1.9 l.) of carbon tetrachloride poured into it. Soil was immediately packed over the treatments to prevent loss of the material by evaporation. The poles were removed and inspected six and ten months, respectively, after the treatment. Live subterranean termites were found in the butt of each pole. Although the material is known to be toxic enough to kill the termites it reaches, the effectiveness of the treatment does not last.

Carbon tetrachloride was also tried for controlling the dry-wood termite by treating infested pole sections. Holes were bored deep into the infested wood every 3 feet (90 cm.) and carbon tetrachloride injected into each under

50 pounds (3.5 kg./sq. cm.) pressure. About ½ gallon (1.9 l.) was used for each 10-foot (3 m.) stub. The holes were sealed after treatment to prevent loss of the carbon tetrachloride. Ten weeks after treatment, one pole, which was extremely porous because of the great number of termite galleries in it, showed 100 per cent kill of the insects. In the other, several groups of live, unharmed insects were found, but the carbon tetrachloride vapors had evidently killed the insects which it reached. No odor of the treatment remained after 10 weeks.

The vapor of *benzene*, or the commercial grade of it known as benzol, is toxic and inflammable. It, too, was used alone and in combination with other chemicals for the so-called gassing treatments. The effectiveness of benzene was tested on poles infested with the dry-wood termite. The liquid was injected under 50 pounds (3.5 kg./sq. cm.) pressure into holes bored into the infested poles. Each 10-foot (3 m.) pole took ¾ gallon (2.8 l.) of benzene. The poles were inspected after ten weeks. The benzene vapors killed the termites which they had reached, but live termites were still present. No odor of the benzene remained at the time of inspection.

Conclusions on volatile liquid fumigants.—Carbon bisulfide, carbon tetrachloride, and benzene were all known to be sufficiently toxic if they actually reached the termites, but the treatments as such were not effective. Live subterranean termites were always found if inspection was made several months after treatment. No odor or evidence of any of these treatments remained. The effectiveness of these volatile liquid fumigants is only temporary. This type of treatment greatly reduces the number of termites infesting the wood, but no permannet protection is obtained. When these volatile chemicals have completely disappeared the termites return from the soil. Although damage to the wood is delayed by this treatment, the results are not economically justifiable. The frequent periodic fumigations which would be necessary during the life of the wood make the cost prohibitive.

The application of volatile fumigants to infestations of dry-wood termites appeared to be promising because these termites live in the wood and have no separate retreat where they may escape the effects of the vapors. The effectiveness of carbon bisulfide, carbon tetrachloride, and benzene was tested by injecting these liquids into the galleries of the dry-wood termites. Wherever the vapors of the fumigants reached the termites they were killed. Nevertheless, occasions when all the termites in the infested wood were killed were rare. The vapors evidently do not diffuse through all the termite galleries. The fumigants kill many of the termites and greatly reduce the population of the colonies, but small, isolated groups of termites remain as a potential source of further damage. No odor or evidence of the treatments remained ten weeks after application. The use of volatile fumigants provides no protection against future infestation.

A mixture of *sodium arsenite* and *benzene* was tried in order to utilize the fumigating action of the benzene and at the same time leave some permanent poison in the termite galleries. It was expected that the sodium arsenite remaining in the galleries would eventually kill the small isolated groups of dry-wood termites which the fumigant might not reach. Tests of a mixture of 10 per cent sodium arsenite by weight in benzene were made on poles infested by the dry-wood termite. Holes were bored into the infested wood and the material was injected into the termite galleries under 50 pounds (3.5 kg./sq. cm.) pressure. The sodium arsenite did not dissolve or emulsify in the benzene and the mixture had to be stirred constantly.

Ten weeks after treatment no odor of the benzene remained, but sodium arsenite was found caked in the galleries into which the mixture had been forced. Most of the termites were killed by the fumigation. Others had died recently, which without doubt was due to the sodium arsenite. Although some few termites were still alive they were apparently weak and ill. All termites in the test sections were affected. The treatment would probably have been completely effective in a longer time, as the permanent protection afforded by the presence of the sodium arsenite was evidently killing the few remaining termites.

FUMIGANTS OF LOW VOLATILITY

Orthodichlorobenzene is a liquid which vaporizes more slowly than those discussed above. The vapor from it is about five times as heavy as air and is non-explosive. The tests with orthodichlorobenzene were all with the dry-wood termite. The material was injected under pressure into holes bored into infested pole stubs. Each hole was sealed after treatment to cut down evaporation. These stubs required ½ and ¾ gallon (1.9 and 2.8 l.) of orthodichlorobenzene for treatment. Inspection was made ten weeks after treatment and the test pieces still retained the odor of orthodichlorobenzene. Live termites were found in one stub, particularly at the top above the highest point treated.

The vapor, being heavy, did not reach these. The other test piece was more porous and accepted a heavier treatment. The kill in this piece was 100 per cent.

A similar treatment was applied in the field to a 25-foot (7.6 m.) pole infested with both dry-wood and subterranean termites. The orthodichlorobenzene was injected at 3-foot (90 cm) intervals from the ground line to the top of the pole. No treatment was applied below ground level. One gallon (3.8 l.) of orthodichlorobenzene was used. The pole was removed and inspected six months after treatment. The odor of orthodichlorobenzene was still present and seemed to have penetrated all the wood of the pole. A faint odor of the material was found in the pole butt 2 feet (60 cm.) below ground line. All the dry-wood termites were killed, but subterranean termites were still found in the pole butt at distances of more than 2 feet (60 cm.) below ground. None could be found, however, where the odor of orthodichlorobenzene had penetrated.

The treatment was effective in killing the dry-wood termite, but the cost, about $4.00 per pole, is too high for general use. Although its effects last for some time, orthodichlorobenzene cannot be considered a permanent protection.

Paradichlorobenzene was first demonstrated as a commercial insecticide in 1915 by A. B. Druckett of the Bureau of Entomology, U. S. Department of

Agriculture. It proved an excellent fumigant for insects in stored products, case-bearing clothes moths, roaches, ants, and miscellaneous household insects. Paradichlorobenzene is a white, crystalline material which looks much like rock salt. It has about the same vapor pressure as the liquid orthodichlorobenzene and produces, like it, a non-explosive vapor about five times as heavy as air. It has a penetrating and persistent odor. The vapor is deadly to insects in general, but is practically harmless to human beings. Because of its volatility, paradichlorobenzene is packed in air-tight containers and should be kept sealed when not in use. Its general use is based on the fact that the vapor is heavier than air and will gradually settle downward and outward. Consequently it is always placed on or above the object to be fumigated. For soil treatments the chemical is covered with a layer of earth to prevent any loss upward by evaporation and to confine the vapors so they will gradually work down into the haunts of soil-dwelling pests.

Paradichlorobenzene is also sold under various trade names such as *P. D. B., Paradi, Paracide, Crystal Glass, Dichlorocide,* etc. For all practical purposes these materials appear to be identical.

The crystalline paradichlorobenzene has the same chemical composition as the liquid orthodichlorobenzene; the effects are much the same. However, the crystalline paradichlorobenzene is more conveniently handled for some types of treatment. Where the crystals can be tightly packed the chemical remains much longer than the liquid form.

Paradichlorobenzene was studied only for control of the subterranean termite. Three poles, one square sawn redwood and two red cedar, infested with the subterranean termite were treated. A trench 1 foot (30 cm.) deep was dug around the butt of each pole and 3 pounds (1.4 kg.) of paradichlorobenzene were packed around the pole and against it. The cross section of the ring thus formed was about 1½ inches × 2 inches (3.7 cm. × 5 cm.). The trench was then backfilled, the dirt being tightly packed around the pole. The poles were removed and inspected six months later. The band of paradichlorobenzene crystals was still present around each pole and was only slightly diminished in size. Its odor permeated all the wood of the pole below ground. No live subterranean termites could be found in any of these poles. Even the dry-wood termites which had galleries near ground level were driven to galleries higher in the pole by the penetrating odor of the paradichlorobenzene.

Paradichlorobenzene shows great promise for palliative control of the subterranean termite. Where the crystals have been well packed it is not unreasonable to expect the treatment to remain effective for one year. This material is being used extensively and apparently successfully in situations which have been difficult to handle with other treatments.

Infestations of the subterranean termite behind concrete retaining walls and in dirt-filled concrete warehouse floors have been difficult to control by chemical treatments. Where damage occurs because of improper construction, the first step should be to correct the error before any treatment is applied. No wood should be left projecting through the concrete into the soil. Since the exact location of the termites in the dirt fill or behind the retaining wall is unknown, it is difficult to treat for them with poisonous solutions. Poisonous dusts (so satisfactory with the dry-wood termite) are known to be worthless here. For such locations the application of paradichlorobenzene crystals would appear to be the most suitable treatment. The vapor penetrates farther than either liquid or dust poisons. The crystals should be applied at the top of the infested fill or wall so the heavy vapor will settle through the soil. The treatment is applied by boring holes through the concrete wall or floor every 4 to 6 feet (1 to 2 m.), packing 1 or 2 ounces (28 to 56 gm.) of paradichlorobenzene crystals in each hole, and sealing it with a dry cement grout. This treatment should last many months, which is a great advantage over other fumigation type treatments.

Paradichlorobenzene should also be a very good palliative treatment for controlling termites entering from the soil between the stucco and foundation of a building. Where the stucco is brought down to or below ground line it should be bonded firmly to the foundation wall to prevent any possible point for entry of termites. This construction detail is seldom properly cared for. If the cost or difficulty of making this repair seems too great, the situation can be handled by periodic applications of paradichlorobenzene crystals. A shallow trench is dug against the foundation wall and paradichlorobenzene crystals at the rate of 1 ounce or more per lineal foot (100 gm./m.) of trench are placed against the wall. Replace the soil in the trench, packing it tightly above the crystals. Such a treatment should be inspected every six months to see that the crystals are still present.

In attempting to add some degree of permanence to these treatments the dosages of paradichlorobenzene recommended for termite control are far heavier than those used as a soil fumigant in agricultural work. The dosages used for agricultural purposes are usually completely volatilized in three to six weeks. These light dosages are considered near the maximum amount which can be used without damage to vegetation. In larger dosages paradichlorobenzene is very toxic to plants and trees, although its action is sometimes very slow. Even in small doses it must not be placed in contact with or very near to living vegetation. The amounts of paradichlorobenzene recommended for termite control would in time damage plants within several feet of the treatment.

Naphthalene is the colorless crystalline material of which moth balls are made. It has a relatively low vapor pressure (0.08 mm. of mercury at 20° C.), and should last even longer than the dichlorobenzenes. Naphthalene is less toxic than paradichlorobenzene, as shown by laboratory tests with the dry-wood termite. Ninety-six hours were required to kill five termites with a saturated naphthalene vapor, while only 72 hours were required with saturated paradichlorobenzene vapor.

Naphthalene was tested as a 5 per cent solution in gasoline. This solution was comparatively cheap. With flaked naphthalene at 17 cents a pound and gasoline at 20 cents per gallon, the 5 per cent naphthalene solution cost about 26 cents per gallon. This mixture is highly inflammable and should be used with caution. Three pole stubs about 10 feet (3 m.) long, infested with the dry-wood termite, were treated with the 5 per cent solution of naphthalene in gasoline. The solution was applied by injecting it under 50 pounds pressure (3.5 kg./sq. cm.) into holes bored deep into the infested wood at 3-foot (90 cm.) intervals. Two of the poles took ¾ gallon (2.8 l.) of solution each, the third, having more termite galleries, required 1½ gallons (5.6 l.). Ten weeks after treatment the poles were cut open for inspection. They all retained the odor of naphthalene. In the two sounder test pieces very few live termites were found. The more damaged piece still had several live insects, both in the heartwood and sapwood. The majority of the termites had been killed by the treatment. In all of these tests live new reproductives from a recent infestation were found in the sapwood. Due to its very low volatility, the action of the naphthalene appears too slow for satisfactory protection. Although the material is more permanent than the other fumigants tested, it evidently does not prevent reinfestation.

General conclusions.—The laboratory and field studies of fumigants and fumigation for termite control have led to the following general conclusions:

(1) *Toxicity.*—Most of the commonly used gas, liquid, and solid fumigating materials were tested and all were found toxic to termites.

(2) *Application.*—The great obstacle to the success of fumigations is the difficulty of reaching all of the termites with the poison vapors. The vapors do not diffuse readily through the termite galleries, hence the termites are able to escape the effects of the vapor even during a fumigation period of reasonable length.

(3) *Subterranean termites.*—In field tests the action of fumigants was found to be toxic to subterranean termites. Although many termites are killed by the treatment, others return from the soil as soon as the volatile fumigant disappears. The effectiveness of the more volatile liquid fumigants disappears very quickly, and all evidence of them is gone in less than three months. Paradichlorobenzene, which gives off a fumigating vapor very slowly, has an effect lasting several months. It is found satisfactory for protecting material from the subterranean termite.

(4) *Dry-wood termites.*—Gaseous fumigants such as hydrogen cyanide and chloropicrin are effective for the control of the dry-wood termite in large timbers only with long periods of fumigation. They are not practical for the control of termites in houses. Fumigation with these gases would be satisfactory for the sterilization of lumber, furniture, etc., especially under the vacuum fumigation process.

(5) *Volatile liquid fumigants,* carbon bisulfide, carbon tetrachloride, and benzene, kill many of the termites in infested timber. Tests have shown, however, that these chemicals do not remain in the wood long enough to reach all the termites by the diffusion of vapors through the galleries. The surviving fragments of the original colonies which remain defeat the purpose of fumigation.

(6) *Less volatile fumigants,* such as the dichlorobenzenes, are more satisfactory. The liquid orthodichlorobenzene is more suitable for treating colonies of the dry-wood termite than is the crystalline paradichlorobenzene.

This treatment is satisfactory for killing the colony, but provides no permanent protection against future infestations after the disappearance of its odor. The cost of this orthodichlorobenzene treatment seems too high to warrant its use on a large scale.

(7) *Naphthalene* as a 5 per cent solution in gasoline injected into termite galleries under pressure shows no promise. It is more permanent than the other fumigants, but it vaporizes too slowly to be effective.

(8) *Permanent poisons* carried into the termite galleries with a liquid fumigant are more effective than fumigants alone. The fumigant kills all termites which it reaches and the permanent poison remains to kill any small groups of termites not destroyed by the fumigant, and to prevent future infestations. A mixture of 10 per cent sodium arsenite in benzol gave very good results.

(9) No fumigation treatment or mixture has been shown to be so satisfactory or so cheap for the control of the dry-wood termite as the dust treatments discussed in chapter 38.

CHAPTER 40

GROUND TREATMENTS

BY

MERLE RANDALL AND THOMAS C. DOODY

The application of chemicals or other materials to the ground was early suggested as a possible method for the eradication of subterranean termites from the soil or for the prevention of infestation of structures by termites. Such treatments are often mentioned in pamphlets containing recommendations for termite control.

Numerous materials and methods have been recommended for this purpose by various persons and in various regions. For no one method or material, however, is there available any satisfactory body of experimental data or field observations, nor is any one of them accepted practice. Indeed, these recommended methods have been abandoned by their authors in several instances, at least, in favor of control by construction methods, because of the lack of authentic information as to the effectiveness of such treatments, as well as on account of the health hazards and other unfavorable features involved in the use of the more widely advocated materials and methods.

At the time the Committee was organized ground treatments were being quite generally used by commercial termite control companies in southern California as a simple remedy for the control of subterranean termites in infested houses. The most used treatment was a 10 per cent sodium arsenite solution, sprayed on the ground under infested houses at the rate of 1 gallon per 100 square feet (0.4 l./sq. m.) of area treated. Such evidence as is available indicates that this particular method of application is of little value, although sodium arsenite is extremely toxic to termites and has proved effective when applied by other methods, as will appear below.

The method of applying a ground treatment, therefore, is of great importance, and much of the Committee's study of ground treatments has been directed toward determining the most effective method of application. Some of the materials which have been recommended for the treatment of open ground areas cannot be used without danger in the closed space under a building. In fact, sodium arsenite, which was at one time recommended by the U. S. Department of Agriculture as most available, and which has been in popular use, is a very poisonous material and, if used at all, should only be used with considerable care, as the Department emphasized.

The three years of the Committee's investigations have been far too short a period in which to determine the possibilities of soil treatments. A satisfactory ground treatment must be more than a temporary palliative to be worth the cost and labor of application. Many materials have been proposed for experiment in the attempt to find an effective but non-poisonous ground treatment. Through the efforts of the Committee many preliminary tests of ground treatments were made to study their effectiveness in preventing termite damage. Our present information indicates that they may prove to be valuable as an adjunct to proper construction for preventing damage by subterranean termites. Ground treatments have shown some value by themselves, and may be used in attempting control of termites where construction difficulties or costs make other types of prevention and repair impractical.

THE RELATION OF GROUND TREATMENTS TO OTHER METHODS OF CONTROLLING SUBTERRANEAN TERMITES

The principal method recommended by the Committee for control of subterranean termites in infested buildings is the repair of faulty construction details, accompanied by a general clean-up of débris and scrapwood under the structure. Complete insulation of all wood from contact with the ground by concrete or masonry foundations, impenetrable to the insects, will, on the Pacific Coast, prevent damage by subterranean termites. Our experience with ground treatments has not been extensive enough to prove them sufficient alone. They are considered at the present time to be of some value as accessory to the above mentioned construction methods of prevention and control. They may be used also as a promising "last resort" method of treatment where the costs of reconstruction do not seem justified.

PRESENT CONCEPTIONS OF GROUND TREATMENTS

The notion of a permanent central nest toward which ground treatments should be directed is not applicable to subterranean termites in the United States as it is to *Coptotermes* in Hawaii. Many attempts made by the Committee to find in the ground a central nest of a colony of the subterranean termite, *Reticulitermes hesperus,* have been unsuccessful. It is probable that many colonies do not continue to have such a nest, and it is certain that supplementary reproductives are far more important than the primary queen as centers of the spread of infestation. Ground treatments can at best serve only as barriers between sources of infestation and the structures to be protected.

Central nests of the oriental subterranean termite *Coptotermes* are commonly found in Hawaii, Formosa, Japan, China, and the Philippines. These nests are often far removed, however, from the wood infested by the colony. This is well shown by an attempt made in Hawaii to trace the galleries in the ground to a central nest. In this case the termite galleries were traced across a block of unoccupied land, and the search for a central nest was given up after following the gallery for more than 100 feet (30 m.) and to a depth of 10 feet (3 m.) (fig. 41).

Our present knowledge shows that the runways of the American subterranean termites through the ground are far more extensive than ordinarily believed. These passageways spread rather generally through the ground and are probably dug in search of new food supplies. The groups of termites infesting one piece of wood, or one location, appear to live quite locally either in or near the wood attacked. However, they are evidently well connected with the complete colony through an extensive system of ground passageways. If this is the correct understanding of the system by which subterranean termites live, ground treatments may kill the local termite group infesting a particular location, but it is quite hopeless to expect thus to kill the entire colony system or to make the ground completely free of subterranean termites.

The present theory of protection by ground treatments, therefore, involves the formation of a soil layer impervious to termites. An effective treatment may be toxic, distasteful, or repellent to prevent penetration of the treated layer of soil by the insects. Such a layer of soil must be thick enough so that it will not be broken through by ordinary disturbances or by the attempts of termites to penetrate it; in fact, the thickness of the soil layer seems to be of more importance than the percentage of poison in the treating solution. Consequently, large quantities of treating solution should be used if an effective ground treatment is to be obtained. Ground treatments not only insulate the structure to be protected from the termites deep in the soil, but they poison or make distasteful the small scraps of wood in the upper layers. The poisoning of this food supply probably helps to discourage termite attack.

To be effective, a ground treatment must be reasonably permanent. This prohibits the use of highly volatile chemicals. Conditions found under the majority of houses investigated show that the ground is usually dry, and this allows the use of water-soluble chemicals with a reasonable assurance of permanence. The water-soluble treatments should last indefinitely if there is no washing out of the ground by drainage or by a high water table.

PRELIMINARY INVESTIGATIONS OF COMMERCIAL GROUND TREATMENTS

As mentioned above, the ground treatment most used in southern California was sodium arsenite, 10 per cent solution, sprayed on the ground surface at the rate of 1 or 2 gallons per 100 square feet (0.4 to 0.8 l./sq. m.). Many failures of this treatment were reported. Failures were also reported after retreatment, and in some cases three and four repetitions of the spray treatment were made before success was attained.

In competition with the spray treatment was the so-called "trench system." A shallow trench about 6 inches (15 cm.) deep was dug along the foundation wall and around the pier blocks, and well poisoned with a 10 per cent solution of sodium arsenite. This was intended to prevent the termites from building their covered runways over the foundation walls to reinfest the structure. Reports show that reinfestation often occurred after treatment. The effectiveness of the trench system was probably about the same as that of the spray treatment.

In San Joaquin County the first termite control work was carried on through the office of the County Agricultural Commissioner. Men from that office applied treatments to the ground under infested homes at cost. Two treatments were used: a 6 per cent and a 2 per cent sodium arsenite solution. The treatments were applied by drenching the soil under the house; 25 to 50 gallons of the 6 per cent solution were used per 100 square feet (10 to 20 l./sq. m.), and 50 to 100 gallons of the 2 per cent solution per 100 square feet (20 to 40 l./sq. m.). After these thorough treatments no infestation by termites has been reported.

Field experiments by the Committee further indicate the effectiveness of relatively large quantities of dilute solutions of sodium arsenite. Sodium arsenite solution was applied to the soil under lumber sills 18 inches (45 cm.) wide and 20 feet (6 m.) long, infested with the subterranean termite. Solutions containing 3 per cent and 10 per cent sodium arsenite were applied at the rate of 10 gallons per 100 square feet (4 l./sq. m.). Inspection six months after treatment showed both treatments effective and the sills no longer infested. More recent experiments show 1 per cent and possibly even 0.1 per cent sodium arsenite solutions to be effective ground treatments if large amounts of the solution are used. With large amounts of dilute solutions a thicker layer of treated soil is obtained, thus giving more effective treatment than small amounts of strong solution. The Committee believes that there is less danger in the use of large quantities of dilute solutions of the poisonous sodium arsenite than in smaller quantities of strong solutions.

A conspicuous warning that the ground has been *poisoned with sodium arsenite* should be left in the form of a permanent sign of wood or metal fastened securely to a permanent structure (Anon., 1932).

A termite control company in San Diego has used a strong solution of copper sulfate for ground treatments, in accordance with recommendations from Australia. The soil is given a generous soaking with the solution. Some of these treatments are now four years old and have shown no signs of failure.

EXPERIMENTS BY THE COMMITTEE ON GROUND TREATMENTS

The first studies of chemical ground treatments for control of the subterranean termite were made by the Committee on infested poles and posts. These first experiments were largely unsuccessful, partly due to the fact that a pole does not offer satisfactory conditions for testing such methods. They were valuable, however, as indicating the difficulties of termite control by ground treatments. Attempted laboratory experiments for the study of ground treatments were not satisfactory. The subterranean termite is difficult to keep in the laboratory except under well controlled conditions. It was found impractical to attempt extensive experiments with them. Furthermore, no simple laboratory routine could approximate the conditions found in the field application of ground treatments.

Practical ground treatments involve many and variable conditions. Each chemical treatment should be tested in several types of soil, under different conditions of soil moisture, in sheltered and exposed areas, and in soil containing natural vegetation and woody material and in soil free from woody particles. Also, each chemical must be tested in several strengths of solution and in a series of quantities of solution per unit of ground area. Only one chemical, in one solution strength, and one dosage, should be applied to any field situation to prove the value of the treatment. Thus the desired study of ground treatments involved more work than could be handled directly by the staff of the Committee.

To cover the extensive possibilities of ground treatments advantage must be taken of every opportunity for testing them. This requires an extensive cooperative program. Definite specifications for the experimental application of ground treatments to infestations of the subterranean termite were issued in 1928 covering all the points listed above and cooperation was solicited. At the time this cooperative experiment was proposed, the county agricultural commissioners were responsible for the licensing of termite control operators in the State of California. Through them we were able to obtain the aid of some of the more reliable operators in the study of experimental ground treatments as used under houses. In addition, a number of organizations having membership in the Committee participated in the cooperative tests.

The suggestions and specifications for experimental ground treatments were based upon reported methods of controlling the subterranean termite, as well as the results of the early experiments of the Committee, laboratory tests of the toxicity of chemicals to termites, and reports of the effectiveness of wood preservatives for preventing termite damage. The method of testing the effectiveness of ground treatment was taken from a report of O'Kane and Osgood (1922), of the New Hampshire Agricultural Experiment Station, of a procedure in which they used trap blocks and stakes of susceptible wood on the treated soil.

RESULTS OBTAINED FROM COOPERATIVE TESTS

Treatment of unobstructed ground areas under houses.—The treatments recommended to the individual operators for experiment covered promising chemicals of a less poisonous nature than sodium arsenite. Because of the relatively high cost of strong copper sulfate solutions, we were unable to interest commercial termite control companies in experiments with it. Consequently, any conclusions as to the value of copper sulfate must be based on the extensive work of one company. Their results indicate that strong solutions of copper sulfate copiously applied give satisfactory ground treatments.

Three groups of experiments with ground treatments of unobstructed ground areas under houses will be discussed.

Group I.—Tests of borax and magnesium fluosilicate were made by one operator on a termite infested area under a house 16 feet x 30 feet (4.8 x 9 m.). The house, located on a side hill, was originally built on 6 inch x 6 inch (15 cm. x 15 cm.) wooden posts set in the ground 7½ feet (2.3 m.) apart and ranging from 3 feet to 8 feet (0.9 m. to 2.4 m.) in height. The area under the house had later been filled with earth and débris to within 2 feet (60 cm.) of the floor level, and the house supported around the outside with a mudsill placed on the ground, and 2 inch x 4 inch (5 cm. x 10 cm.) underpinning. Some lumber and débris from the reconstruction of the house which had been left on the ground were heavily infested and practically destroyed by the subterranean termite. The 6 inch x 6 inch (15 cm. x 15 cm.) posts were so badly damaged and the mudsill so heavily infested that all of the posts, nearly two-thirds of the mudsill and part of the 2 inch x 4 inch (5 cm. x 10 cm.) underpinning had to be replaced. The covered runways and towers of the subterranean termite were in evidence throughout the area, and the soil was full of termite passageways. In preparation for the test the 6 inch x 6 inch (15 cm. x 15 cm.) posts were broken off below the ground line and covered with earth. The test area was then divided into four experimental plots 7½ feet x 16 feet (2.3 x 4.8 m.), and all wood cleaned from the surface of the test area before treatment.

One plot was treated with 5 per cent and another with 10 per cent magnesium fluosilicate solution. The third and fourth plots were treated with 5 per cent and 10 per cent borax solutions. The experimental treatments were applied at the rate of 10 gallons per 100 square feet (4 l./sq. m.) of ground surface. In the clay loam soil a ready penetration was obtained, giving a treated soil layer about 1 inch (2.5 cm.) thick. Six trap blocks of sapwood were placed on the surface of each test plot to test the effectiveness of the treatment.

The trap blocks were inspected once every three months. After one year there had been no termite attack on any of the blocks and no evidence of termites on any of the test plots. At each inspection subterranean termites were found in the soil around the house, proving that the insects were still present. Some fungus growth was found on the plots treated with magnesium fluosilicate, particularly on the 5 per cent treatment. No evidence of fungus was found on the borax treated plots.

Since the installation of these tests the operator who made them has used borax extensively for ground treatments. No cases of penetration of the borax treated soil by termites have yet been reported.

Group II.—In this group of experiments the operator tested magnesium fluosilicate. Five houses infested with the subterranean termite were treated by the trench system. A trench from 6 inches to 1 foot (15 cm. to 30 cm.) deep was dug along the foundation wall and around the pier blocks and treated with a 10 per cent solution of magnesium fluosilicate at the rate of approximately 1 gallon per lineal foot (12 l./m.) of trench. Where it was possible to determine the penetration of the solution the treated soil layer was about 4 inches (10 cm.) thick. All wood was carefully cleaned from the ground areas under the houses. Trap blocks were placed on the ground in the treated trenches and in the untreated areas. Periodic inspection of all trap blocks was made, the last inspection being made fourteen months after the treatment. Slight termite attack was found on some of the check trap blocks placed on the untreated soil. No evidence of termites or their attack was found on the trap blocks placed on the treated soil, but there was some fungus attack in these test blocks.

Another infestation where the house had been built over the stumps of four trees was treated with a 5 per cent solution of magnesium fluosilicate. The tree stumps and all miscellaneous wood were removed and the soil well soaked with the treating solution. Many details of construction were corrected at the same time. There has been no recurrence of termite infestation since the treatment.

Group III.—Other cooperative tests of ground treatments on infested houses are being carried on. In some cases we have not been able to obtain as complete reports as those given above, and in others the experiments have been installed too recently to warrant any conclusion.

One experimenter has obtained very promising results with the use of a strong solution of common salt (sodium chloride). The cheapest grades of rock salt make inexpensive ground treatments. Further work should be carried on with this material, as this experiment has been in progress for only a short time.

Another large termite control company has experimented with several materials for ground treatments. They report successful treatments with ammonium fluoride, sodium fluoride, and sodium fluosilicate. These chemicals are said to give ground treatments practically equal to those obtained by use of the strong poison, sodium arsenite.

One operator reports successful ground treatments with kerosene emulsion containing 1 ounce of sodium arsenite per gallon (8 gm./l.) (approximately 1 per cent). His routine for obtaining better penetration of the treatment is interesting. If the top soil is in the form of dust, the treatments do not soak into the soil readily. In that case he first waters the soil, wetting it thoroughly. He then applies a treatment of 3 gallons of kerosene emulsion per 100 square feet (1.2 l./sq. m.). This treatment is allowed to soak into the soil, but before it has dried a second treatment is applied. The actual dosage is 6 gallons of kerosene emulsion per 100 square feet (2.4 l./sq. m.), which has proved to be an effective treatment.

The experiments in these three groups of tests are to be considered only preliminary and exploratory in nature. The results considered in connection with those previously given for treatments with sodium arsenite bring out certain important points:

(1) A number of materials are effective if properly applied, while the most toxic (sodium arsenite) is ineffective if improperly applied.

(2) Among the materials seemingly effective are several which are non-toxic, such as borax, or relatively non-toxic, as magnesium fluosilicate.

(3) Further testing is necessary to determine the permanency of such treatments.

Ground treatment plot tests.—The Committee proposed to several cooperators the installation of ground treatment test plots. The purpose of these plots was to be purely experimental, and the cooperator was informed that such an experiment would be of no direct benefit for control of termite infestations. We had hoped to cover a wide field of treatments and varied dosages in these tests to determine the limits of effectiveness of doubtful materials. The Standard Oil Company had a situation suitable for tests of this type. Two ground treatment test plots were installed by it in southern California.

Test I.—This test plot was known to have an unusually heavy termite infestation before the treatments were applied. A thin layer of heavy refinery residuum had previously been applied to the plot. It was necessary to break up the soil before applying the treating solution in order to permit ready penetration. The test area, approximately 15 feet x 25 feet (4.5 m. x 7.5 m.), was raked clean, turned over with a spade, and leveled. The area was then divided into 5-foot (1.5-m.) squares, which were marked with iron stakes. Part of these sections were treated with a "kerosene" which was applied with a garden sprinkler in quantities of 20 to 40 gallons per 100 square feet (8 to 16 l./sq. m.) of ground area. One trap block was then placed at the center of each treated and untreated section.

The trap blocks on the untreated sections were inspected eight months after treatment, when three of the four blocks were found infested with the subterranean termite, *Reticulitermes hesperus*. The fourth block showed evidence of attack, but was not infested at the time. At 10 months three of the four blocks placed on the untreated areas were infested. The blocks were removed from the untreated areas one year after placing in position.

Inspections of the trap blocks on the treated sections were made simultaneously with those on the untreated sections. In addition, other inspections were made fourteen, sixteen, and twenty-six months after placing, and the test was then discontinued. Up to that time no trap block on any treated section had been attacked by the subterranean termite.

Test II.—This location was selected because of the proximity of eucalyptus stumps infested with subterranean termites. All areas in the plot were within 50 feet (15 m.) of infested stumps. Numerous small pieces of wood within the immediate vicinity showed evidence of previous infestation. An area approximately 40 feet x 50 feet (12 m. x 15 m.) was raked clean, leveled, divided into 2½-foot (75-cm.) squares marked with iron stakes, and treated with various solutions, as shown in the chart (fig. 131). Pine trap blocks were placed at the center of each test square.

Inspection ten months after treatment showed thirty per cent of the trap blocks on untreated sections infested. At the end of sixteen months all trap blocks on the untreated sections had been found infested and were removed, leaving the blocks on the treated sections as the only food available.

Inspection of all blocks was made eight, ten, and twelve months after placing; and for blocks on treated squares fourteen, sixteen, and twenty-six months after placing. Blocks found infested are marked with the date on which infestation was noted (fig. 131). Four blocks found to be infested at the end of eight months were found to be free from infestation at the end of ten months. Termite infestation was found in the vicinity of the test plot during each inspection. Evidence of termite attack and one dead termite were found in the block in treated area No. 13 at the end of twenty-six months; no evidence of termites was found in the blocks on the other treated areas. The infested block was located on an area treated with 5 per cent sodium arsenite solution—4 gallons per 100 square feet (1.6 l./sq. m.). At the time this treatment was applied it appeared that it would be unsatisfactory because of the difficulty of uniformly applying such a light treatment to the soil. It was noted also that practically no penetration of the soil was obtained with this treatment.

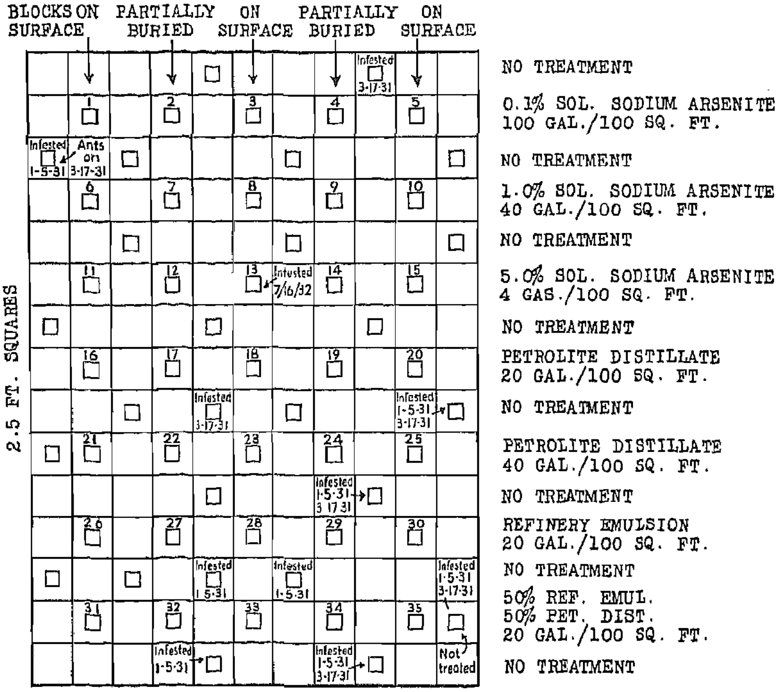

Fig. 131. Arrangement of test sections, test No. 2, for ground treatment studies in cooperation with the Standard Oil Company of California, at El Segundo, California.

The blocks on the treated sections are still in position. The area is isolated, and the test can probably continue indefinitely.

Soil treatments by fumigation.—Reports by Mr. E. M. Ehrhorn (p. 293), of Honolulu, show considerable success in eliminating the subterranean termite, *Coptotermes formosanus*, from infested soil by fumigation. His method of treatment is as follows: Trap stakes are driven into the infested soil. After the termites have had time to establish themselves in the stakes, each stake is removed carefully so that the termite galleries from the soil to the stake will not be destroyed. Carbon bisulfide, carbon tetrachloride, or other liquid fumigant is then poured into the hole and the stake replaced.

The liquid fumigant, or the heavy vapors of it, are intended to diffuse into the termite galleries in the soil and exterminate or discourage the insects. By applying the liquid fumigants to the stake holes periodically it is said that the soil can be kept free from termites. Ehrhorn's experience (p. 293) has shown that carbon bisulfide is much the most effective material for such fumigations.

Experiments with this method of applying liquid fumigants were undertaken by the Committee too late for inclusion in this report. Experiments with one application of liquid fumigant to poles infested with subterranean termites showed no permanent value for control of the insects. These tests are discussed in detail under benzol, carbon bisulfide, and carbon tetrachloride in the chapter on fumigants. At first the fumigants appear to have eradicated the insects, but after the volatile fumigant has disappeared the same or other species of termite returns from the soil to infest the poles.

Field observations on infestations in soil-filled porch areas which had been treated with the so-called gassing treatment (an application of mixed volatile fumigants) by commercial termite control operators showed only temporary value. For some time after treatment the fumigation appeared to have controlled the termites in the soil, but six months after there seemed to be no decrease in the infestation.

The only fumigant which was found effective against subterranean termites for the duration of the test period was paradichlorobenzene. This is also discussed under fumigants (chap. 39). This crystalline material is much more permanent than the liquid fumigants, and the heavy vapors from it either kill the termites or drive them away. Paradichlorobenzene has been used for treating the infested soil under houses with much reported success. The details of treating general ground areas with this product are not known. Where it has been used along foundation walls and in holes from which stumps have been removed, ½ to 1 ounce per lineal foot (50 to 100 gm./lineal meter) of trench treated has given good results. The crystals should be put in a shallow trench or in a hole and covered with tightly packed earth to prevent loss by evaporation. Paradichlorobenzene has been particularly adaptable to situations where it was evidently impossible to get a thorough ground treatment by application of solutions. The permanence of this treatment depends on the amount of the chemical applied. The treatment should be watched carefully at six month intervals to see that some of the crystalline material remains in the soil.

Ground treatments and vegetation. — All ground treatments discussed herein, when applied in heavy enough dosage to insure termite control, are toxic to vegetation. Often a ground treatment is desired which can be properly and effectively applied under a house near which shrubbery is growing, without damage to the plants. (Some of the early failures with ground treatments have been traced to dosages applied too weak and in too small a quantity for fear of killing nearby plants.) Most of the satisfactory termite treatments are well known to be toxic to plants. Sodium arsenite is much used as a weed killer; borax is detrimental to plants in extremely small percentages in the soil; copper sulfate present in more than small amounts is destructive;

reports show that plants were damaged by soil treatments with 5 per cent magnesium fluosilicate, and even sodium chloride in the heavy dose required for termite control would prohibit the growth of vegetation.

At the present time none of the soil treatments in use can be called harmless to vegetation. It is true that some successful ground treatments have been applied without damage to nearby vegetation; these have been with creosote, sodium fluosilicate, and magnesium fluosilicate; but freedom from damage to nearby plants cannot be guaranteed, even with these treatments.

Commercial Proprietary Products for Ground Treatment

Three commercial proprietary materials for the treatment of soil infested with termites have come to the attention of the Committee. None of them have been tested by the Committee.

Antimite.—This is a product of the Antimite Company of St. Louis, Missouri, and is sold specifically for termite control by ground treatment. *Antimite* is a dry salt which is made by mixing sodium fluoride, dinitrophenol, and sodium arsenate. The composition is similar to salt type wood preservatives made from these same ingredients. The material is used as a 4 per cent solution in water (10 pounds to 30 gallons [4 kg./100 l.] of water). The recommended application is a generous drenching of the infested soil.

Fluorex.—The American Fluoride Corporation of New York sells two *Fluorex* products for termite control. They describe their *Fluorex V* as a modified sodium fluosilicate, which is sparingly soluble in water. *Fluorex S* is a magnesium base fluosilicate, which is water-soluble. The manufacturers recommend them for ground treatments in 5 per cent and 10 per cent solutions, respectively.

Terminix.—The E. L. Bruce Company of Memphis, Tennessee, manufactures *Terminix,* a liquid developed specifically for termite control work. It is composed of orthodichlorobenzene, toxic solvents, and a toxic salt intended to prevent permanently the deterioration of wood. The product is light in color and has been developed to penetrate readily both wood and soil. The *Terminix* treatment is applied only by application companies licensed by the E. L. Bruce Company. It is applied under a five-year guarantee and inspection service in which the application companies are backed by the manufacturer.

The treating routine of the *Terminix* treatment requires complete insulation of all wood from ground contact, generous application of *Terminix* in trenches along the foundation walls, and a spraying of all exposed wood with the treatment.

Ground treatments for poles.—Very extensive but more or less disconnected experiments were carried out by the Committee and cooperating members on infested poles in the ground, using a variety of materials and methods. As a means of testing the efficacy of ground treatments with a view to their use in connection with buildings, poles are unsatisfactory for a variety of reasons. Among these are (1) the fact that any satisfactory check on results requires the removal of the pole, which is often difficult or impossible; (2) the fact that the complete envelope of poisoned soil necessary to provide protection is extremely difficult to attain in practice; and (3) the difficulty in interpreting results when obtained due to the presence in the pole of a large central core of unpoisoned wood to which the termites of the periphery may retreat.

As a means of increasing the service life of untreated poles already in the line, the results obtained, while generally inconclusive, indicate that the methods might be of considerable palliative value in the case of untreated poles in areas of heavy infestation. As pointed out elsewhere (chap. 49), no large users have found ground treatment satisfactory.

Conclusions on Ground Treatments

(1) Ground treatments by themselves should not be depended upon as a fundamental method either for the prevention of termite damage or the eradication of termite infestation. Proper construction and the insulation of all unprotected wood from ground contact is generally conceded to be the best method of preventing damage by subterranean termites.

(2) Ground treatments must still be considered as in the experimental stage. The evidence presented here indicates that at least temporary protection from subterranean termites can be obtained by ground treatments properly applied. We believe, therefore, that further experimentation with ground treatments as a supplemental method, especially with chemicals not poisonous to man, would be justified.

(3) Due to their strongly poisonous nature, sodium arsenite and other arsenicals are not recommended for this purpose. However, if sodium arsenite is used, the health hazard can be reduced and the effectiveness of the treatment increased (p. 475) by the use of larger amounts of dilute solutions (2 per cent and less), and by placing a conspicuous, permanent warning sign showing that the soil has been poisoned.

(4) No effective material has been tested sufficiently to make it possible to state that it will not kill plants.

(5) Periodic inspections of structures to be protected (p. 552) should by all means be continued whether ground treatments have been applied or not.

PART III

TERMITE RESISTIVITY OF WOOD AND BUILDING MATERIALS

CHAPTER 41

A STANDARD BIOLOGICAL METHOD OF TESTING THE TERMITE RESISTIVITY OF CELLULOSE-CONTAINING MATERIALS

BY

CHARLES A. KOFOID AND EARL E. BOWE

INTRODUCTION

The investigator of termite structure finds that the antennae of termites have ample provision of sensory organs interpreted as olfactory, that their mouth parts have specialized groups of sense organs which may be gustatory, and that the mandibles with which the minute particles of wood are snipped off in the process of feeding are intensely innervated (chap. 1). The observer of termite behavior and the inspector of termite damage both find evidences of selection of particular species of wood where several are available, and of attack within the species confined to particular pieces among many in comparable exposures. Thus, in the furniture store (p. 226) the redwood false floor was merely traversed by *Kalotermes minor* to enter and destroy two fir flooring boards of many, and the fir was left to enter cherry. In another instance *Reticulitermes hesperus* built tunnels up a redwood post to a height of 2½ feet and for 5 feet along a redwood stringer to enter and destroy one of fir, and repeated the process of destruction on a replaced fir stringer, but never entered the redwood. In one of our early experimental tests *Kalotermes minor* placed in groups of fifteen in ⅜-inch bores of various unseparated wood samples and corked in, bored their way out of these samples and into a single sample of Douglas fir until 392 of them had selected this single block for their residence, in preference to any of the many others immediately at hand. A single Douglas fir unseasoned and fragrant 2 inch x 8 inch timber lying among others on top of a load of similar pieces at a building site in a southern California village at the height of the swarming season of *Kalotermes minor*, had no less than 14 pairs of reproductives dug in and sealed in within twelve hours, whereas other pieces alongside this one had at the most only 2 pairs.

Examples might be multiplied of the selective action of termites in finding sites for new colonies, and of selectivity in both the range and the direction of extension of old colonies. Some of these seem almost uncanny in their range, in the distances traversed, and particularly in the evidences of selectivity.

The factors which determine these selections are complex. They differ for different species of termites, for the different stages of the life cycle, and for the different environments. Some of the factors certainly involved, and others probably involved, in selection are the moisture content of the wood, both free and bound; the amounts and chemical nature of the various extractives; the physical qualities of the wood resulting in density, hardness, or other properties influencing its resistance to the jaws of the termite; the rates of growth of the wood in the spring and the summer zones of the annual rings; the differences between sapwood and heartwood; the nature and amounts of the nutrient substances which favor the growth of fungi in the wood, especially in the walls of the burrows; and the nature and extent of preexisting fungus attack. Temperature exercises a controlling effect on many termite activities. Thus, in Honolulu it is reported that the superheated attics of wooden houses are especially liable to intense destructive activity by *Coptotermes*. In California the earthen tunnels and towers of *Reticulitermes hesperus* are best developed in warm basements, near furnaces, steam pipes, on the sunny side of fences, and other locations where sustained warmth prevails.

Termite resistivity of wood can be regarded as the component of all such factors, and of such others not enumerated or known, both favorable and unfavorable, as may be interacting in any given case. The assessment of such resistivity, however, is as yet not sufficiently under scientific or practical control to be of either precise scientific or proven practical value in all cases, though clearly so in some

One of the main reasons for variability in field tests lies in the fact that both in nature and practice the recorded or observed resistivity of a given piece of wood to termite attack is determined, at least in part, by the choices available to the termite at the time and place. A given piece of wood under one set of conditions as to adjacent wood available remains untouched, but is attacked under other conditions of surrounding wood, in the same place.

In attempting to determine resistivity of wood either by precise laboratory methods or under practical field conditions, two aspects of the problem are encountered which are usually inseparably interlocked under most field service tests, but which may be isolated under laboratory control. They are, on the one hand, the preferences exercised by termites among available offerings of wood and locations, both in the original location of colonizing pairs and in extensions of existing colonies, and, on the other hand, the actual relative usability of woods offered, as recorded by actual volumes excavated from test blocks uniformly exposed to termite action, with the elimination of all choice.

All field tests of necessity involve the preferential factor, since test timbers must be exposed in locations where termites are already present and have available natural food. The natural environments have many variable factors. As a result of these variations a given test timber may not be attacked at one time or location, but will be in another one seemingly similar.

Such field tests have a practical value in so far as they afford adequate time for the settlement and expansion of new colonies, or for the invasion by old, well established colonies of termites, for fungus attack, and for the climatic effects of weathering upon the wood. It is also essential that the conditions of the test equal in degree of severity the maximum, or at least a wholly adequate exposure to, attack. Examples of such exposure are to be seen in the International Tests at Panama (chap. 36). In such tests the preferential selection or avoidance has full play, and exposure is at or near the maximum one occurring in nature. Natural or treated woods which are not attacked over a period of years under severe conditions, with the attendant weathering which will adequately test the persistence of deterrent natural extractives. or of introduced chemical treatments, are definitely termite-resistant.

Natural woods and some chemically treated woods which remain undamaged for several years in localities where susceptible woods fail, but which are attacked after some years of service or soon destroyed in other localities, are not to be rated as termite-resistant, but only as termite-deterrent. Obviously, this deterrent capacity will range over a wide amplitude of efficacy, from a slight and very uncertain protective value to an approach to complete resistance. Some durable woods belong in the deterrent category. Some chemical treatments, such as that by zinc chloride, have only a slight deterrent action for termites. Some forms of treatment, such as brushing on creosote, have only a slight deterrent effect, and for a short time, while dipping and boiling increase and prolong the protective effect, but do not arrive at the more complete termite resistivity possible with the pressure treatment. In laboratory tests, surfaces of wood brush-treated with toxic chemicals, or untreated sapwood covered with toxic paper of heavy weight, exposed to continuous attack of confined termites, reveal the capacity of even so small a number of termites as fifteen to penetrate a relatively thin protective layer of treated wood or of poisoned paper before all of them are killed.

The second type of test is that involving non-preferential or forced feeding under scientific control, in which the termites are placed in the wood or other material to be tested and are retained there until the effects of the particular diet upon their destructive activity and duration of life are apparent. Conditions in field tests essentially similar to this may occasionally occur in nature, but termites can generally elude such limitations.

ESSENTIALS IN A LABORATORY TEST OF RELATIVE TERMITE RESISTIVITY OR DETERRENT ACTION OF CELLULOSE-CONTAINING SUBSTANCES

The purpose of such a test is to determine the amount of wood or cellulose destroyed by controlled termites under approximately uniform or similar conditions, by a method which can be repeated for verification and comparison. The biological considerations are an approach to normal colonial life in the termite colony, natural conditions, numbers sufficient to reduce sources of error to a minimum, and a length of time adequate for considerable excavation of burrows, or of death by starvation.

Obviously, the best method would be to use normal complete colonies of uniform numbers and ratios of component castes. This is in practice unattainable because of the difficulties of securing such colonies in sufficient numbers and uniformity. The next step would be to set up colonies of uniform numbers with, in addition, soldiers and king and queen, but these added castes are only a drain on the workers, or nymphs, in the colony as a feeding unit, although they may exercise some as yet unknown stimulus to normal activity upon the feeding nymphs, or workers. As an attainable practical method it was decided to use 100 feeding nymphs at the maximum period of their activity, that is, in the last two larval instars.

History.—A review of previous investigations of the comparative resistance of wood to termite attack does not reveal any quantitative method for measuring the actual volume of wood excavated under uniform conditions of laboratory control. Oshima (1919) estimated the relative resistance of a species of wood by comparing the number of sample blocks attacked with the total number of blocks of the wood exposed in the test. In one test he placed blocks of several species of wood 2 inches x 2 inches x 15 inches adjacent to each other in the ground. The termites had a choice of the woods. Snyder (1924*a*) has reported results from placing test stakes in the ground in which termites were given a choice of wood and wood treatments. These field tests all lack the quantitative aspect, since there is no control over the number of termites working in the wood. They are valuable as field tests of endurance under exposure to termite attack where selection by the termites is possible. They do not make possible a quantitative test of relative termite resistivity. Wolcott (1924) weighed the pellets of the termites in the woods tested. He used varying numbers of termites for different pieces of wood. Numbers of alates developed during the test. This affords a sort of quantitative test, but is subject to the variables arising from varying amounts of lignin and from pellet feeding.

Objectives.—It has been considered desirable to ascertain the relative resistance of various woods, both treated and untreated, against attack by termites. It is desirable to learn something not only about freshly felled wood, but also about wood which has been exposed to seasoning and weathering for a period of time under various conditions. An obstacle to the determination of such relative resistance has been the lack of a suitable method of measuring the volume of wood excavated. This report gives the details of a laboratory method which has been developed to meet this requirement and its application to tests of termite resistivity on some commercial woods.

It is realized that the method which has been developed can give an exact quantitative measure of the excavations of a specified number of termites within a definite period of time only if the full number is maintained or prorated. The resistance of the wood, however, involves not only the amount of excavation but the repellent action causing termites to leave the wood, and the depressing and lethal effects of its extractives on termites and their intestinal fauna and flora, and on the fungi growing in their pellets and in the wood. The total volume of excavations accomplished by a colony started with 100 termites working for 60 days is therefore a fair quantitative measure of relative termite resistivity under normal physical and biological conditions.

Species of wood tested.—Our experimental work included not only several species of wood, but within the species samples possessing varying chemical and physical propensities, in order to find what relation, if any, existed between these factors and the amount of wood the termites excavated. Only the more evident physical characteristics of the species tested were recorded. In some woods the extractive content, which has been found by Hawley, Fleck, and Richards (1924) to have an important relation to the durability of those woods, was determined for us by the Forest Products Laboratory of the Forest Service of the U. S. Department of Agriculture, Madison, Wisconsin, through the cooperation of Mr. C. P. Winslow, Director, and the findings are used by his permission.

The information obtained by our tests indicates the reaction of termites to wood containing various percentages of natural preservatives and to wood having varying physical properties. The results reported do not necessarily indicate the entire range of these factors within a species of wood. It was not possible with our resources to extend this phase of the work to a wider range of samples. The information presented may, however, form a basis for comparison with the determinations of other investigators.

BIOLOGICAL FACTORS IN LABORATORY TESTS OF RELATIVE TERMITE RESISTIVITY

After many tests of laboratory methods of maintaining termite colonies of *Kalotermes minor, Reticulitermes hesperus,* and *Zootermopsis angusticollis,* the first named species was selected as the best one to be used as a test species, for the following reasons: (1) It habitually occurs in sound wood and can therefore be used for testing wood in sound condition. (2) It is a species of major economic importance, belonging to a genus with wide distribution. (3) It is very amenable to laboratory conditions. (4) It is readily obtainable in quantity. There are several disadvantageous features in its use, due to the facts that its colonies are often small, that several to many colonies may occur within a short distance in one pole, and that their burrows are usually so interlaced or overlapped that colonies cannot be kept separate in collecting.

The termites used in tests must be kept during the test under as nearly natural conditions as possible. This means in a moist atmosphere, in the dark, protected from sudden changes in, or extremes of, temperature, and with as little mixture of colonies as possible. In collecting termites for test use, the pole was sawn into 2- to 4-foot sections and split carefully; the termites were shaken out on cloth, the lot from each section being kept separate from all others and transferred at once into fiber mailing cases with metal ends, packed with moistened filter paper, and protected from heat or cold. This procedure limits mixing colonies, prevents dessication, and tends to suppress cannibalism. The group is held together in quarantine for up to a week before utilization, in order to eliminate weaklings and injured individuals, and to reduce antagonisms due to chance mixtures of colonies.

In making up a test group, 100 individuals of the sixth and seventh instars, the more mature nymphal stages, were selected. All reproductives, both primary and secondary, and all soldiers were rejected. No nymphs with long wing pads were used, since these are about to transform into alates, and suspend active eating at this period. All nymphs off color or off size of abdomen, or with other evidences of weakness were rejected, since these have their intestinal contents reduced by the anal feeding of their associates and may soon die. All nymphs showing the whitish opacity indicating approaching molt from one instar to the next were also rejected, since they also suspend eating during the molting period. These eliminations give a fairly uniform group of the largest and most active stages of these termites in the period of their greatest feeding activity, and these only were used in our tests.

Another very essential precaution in handling termites for test use is the avoidance of mutilation and damage to any of the appendages or to the body proper. Cripples tend to induce cannibalism, which disrupts the normal feeding processes of the colony. To prevent such damage the quarantined groups of several thousand termites, when subdivided into lots of 100 and distributed to the test blocks, were handled only on smooth sheets of cellophane. Funnels or troughs of this substance were used to guide the termites into the bore of the test blocks. Vagrant individuals were directed only by soft camel's hair brushes, all tools such as forceps being avoided.

Except for the brief period in which the termites were shifted into their new quarters in the test blocks, they were confined in a moist atmosphere, with moistened high grade filter paper for food, with some admixture of pellets from their burrows so as to provide for the quick growth of fungi in the paper. By these precautions it was feasible to stock the test blocks with 100 healthy advanced nymphal stages actively feeding, and with a minimum of disturbance to their routine of living and feeding.

The maintenance of a constant number of active termites in a standard test block over a given period of time is difficult and can rarely be attained in practice. A varying amount of loss of life seems to be associated with the nature of the species of wood and with the variations within the species and samples of wood tested. The biological factors involved in the loss of individuals are complex and not readily analyzed. Some of them are more evident than others.

Cannibalism is not infrequent among isolated termite groups under laboratory conditions. It affords an immediate supply of protein, so essential in the diet, but present only in a very small quantity in the normal non-fungused wood. To an unknown extent the effect of cannibalism will be to reduce the activity in excavating and feeding on wood.

A step in the development of cannibalism is anal feeding. Termites are observed to eat freshly extruded pellets and even to take them as they are extruded. The intestine of the normally feeding nymph, or worker, is distended with fluid filled with Protozoa. Anal feeding upon this fluid is supposed to occur in nature. Individuals thus fed upon sometimes become exhausted and dwarfed by this process and ultimately die, and are eaten by the others. The extent to which cannibalism occurs in laboratory colonies seems to vary greatly. It introduces a disturbing and unavoidable source of variation in the quantity of excavation.

Another source of variation of considerable extent is the voluntary leaving of the test block by some individuals. It is not as yet known whether or not mixture of colonies in the test group results in the expulsion of minority representatives. It may be that the change in available diet when individuals of the test group have been moved from one species of wood to another to which they are less acclimatized leads them to abandon the new feeding ground and to explore for a more favorable one. It is fairly common to find newly established groups in the test blocks opening one or more burrows to the surface within the first twenty-four hours after installation. This exit is usually sealed. It may be used for expelling pellets. It is occasionally left open in a moist dark room. Termites wander out from such exits into the glass dishes, from which they cannot escape. Many of them return, but others die.

Another source of reduction in the actively feeding membership of the test groups of termites is the transformation of certain individuals into secondary reproductives. This is initiated within a short time after isolation of the group apart from the customary king and queen. In our series of tests 94 groups of 100 termites each were isolated. At the end of 60 days there were 91 individuals so clearly changed by those structural modifications which mark the supplementary reproductives that they could be picked out. A few were fully developed. Others had only the beginning of pigmentation. They were found in 65 of the 94 groups. Of these 65 there were 38 with 1 only, 25 with 2, and 1 with 3 reproductives in various stages of differentiation.

In all attempts to determine the relative termite resistivity of natural woods by laboratory methods it is important not only that uniformity of method and of environmental conditions be maintained throughout the testing period, but also that the tests be coincident in time. The reason for this is the effect of the seasonal cycle of the termites themselves upon their activities. As shown in Table 41, midwinter tests on the Ponderosa pine test blocks PP8 (heartwood) showed an average excavation of 3.5 cu. cm., while spring tests rose to 4.0, an increase of 14 per cent, under similar laboratory conditions. The tests of Ponderosa pine sapwood rose from 4.1 to 5.37 cu. cm., an increase of 31 per cent.

Another important biological factor operating to accelerate or depress the rate of excavation of selected groups of termites used in test blocks is the effect upon the activities of the nymphal stages of approaching molt, especially of the last molt. At the approach of molt there is a temporary cessation of feeding. Molting is accompanied by the shedding of the lining of the hind-gut, with an almost complete loss of the Protozoa. Refaunation of the digestive tract follows with the resumption of anal feeding, by which the Protozoa are re-acquired from colony mates. During the several weeks that these digestive readjustments are in progress the termites cease eating. Prior to the molt the body becomes more whitish opaque, and nymphs approaching the molt can be excluded from test colonies. They may, however, appear in the colony after the test has started, and it is impossible to avoid their appearance.

The most important molt of all is that of the seventh, or last, instar to the winged, sexually mature alates and to a few of the highly differentiated soldiers. This change, which is almost a metamorphosis, involves a greater volume of tissues than do the previous molts; for example, in the muscles for flight and the wings in the alate, and the greatly enlarged head of the soldier. Furthermore, the tendency for swarming to occur at certain rather restricted seasons tends to concentrate this molt in relatively brief periods.

Tests of relative resistivity made prior to the swarming season are therefore liable to make use of termites at the very height of their voracity. However, when the preparation for the molt begins, their feeding will cease and the test be correspondingly disorganized. For this reason tests should not be undertaken in the month just prior to the major swarming seasons, or if so undertaken, the seventh instars should be excluded.

Another source of depletion of the actively feeding members of the test groups is the differentiation of soldiers, which do not excavate wood, but are fed by the nymphs. The soldiers are metamorphosed at the molt of the fourth, fifth, and sixth instars, but rarely at the seventh instar. They are differentiated usually at about the time that the seventh instar metamorphoses to the alate.

The total loss of individuals from our 94 test lots, totaling 9,400 termites, at the end of the 60-day test was 3,447, or 37 per cent. None of this loss was due to the emergence of soldiers. Only 2 individuals were lost due to metamorphosis to alates. Migration out of the test block and death on failure to return resulted in a loss of 509 individuals, or 15 per cent of the total loss. The remaining 22 per cent of loss was probably due to a combination of factors, one of which was cannibalism, and another the excessive anal feeding. The relative weight to be given to the two is perhaps unimportant, since both probably arise from a shortage of protein food in the newly established test block. Of the 509 dying outside of the test blocks 225 had been partly eaten.

There was a notable contrast among the different species of wood in the number of termites abandoning the test block, as shown in Table 40.

TABLE 40

TERMITES LEAVING TEST BLOCKS

Species of wood	Number of blocks	Number of termites in test group	Number of termites leaving test block	Per cent leaving
Ponderosa pine sapwood	14	1,400	1	0.07
Douglas fir heartwood	25	2,500	4	0.16
Ponderosa pine heartwood	15	1,500	100	6.67
Redwood heartwood	35	3,500	400	11.43
White oak	3	300	1	0.33
Southern pine	1	100	1	1.00
Black gum	1	100	2	2.00

The data of this table are suggestive of a considerable range of repellent action in the different species of wood represented by test blocks, on the assumption that all departures are due to the dislike of the termites to the wood. In making up the test groups five different lots of termites were used. There is no evidence that the variations in the number of migrants are correlated with these lots and thus to differences in antagonisms occurring within the group because of differential mixtures of colonies. Our observations indicate that following admixture of colonies for a few days antagonisms fade out, probably because of the blending of differential odors. Foreign nymphs will be accepted at once in a colony if smeared with the intestinal fluid of individuals of the colony. The major cause of migrations and cannibalism in our tests should be sought elsewhere than in intercolonial antagonisms.

Observations on colonies of *Zootermopsis* fed on filter paper show that cannibalism is high until the paper is colonized with molds, and drops off quickly after the fungi are abundant. It seems certain that the variable survivals in our test blocks are associated with the primary protein necessities in the diet of the termites and possibly with variations in the rate and amount of growth of fungi. In long established colonies these necessities are apparently met by the contributions of the associated fungi. In the absence of a sufficient amount of such growing fungi the termites turn to anal feeding and cannibalism to meet the necessity.

The work of Sherrard and Kurth (1933*a*) has shown the deterrent effect of redwood extractive on the growth of the wood-dwelling fungus *Fomes annosus*. This extractive may be deterrent to other fungi also. If so, the exceptionally large number of migrants (11.4 per cent) from redwood test blocks, and the high total death rate in the 35 test blocks, namely, 65.4 per cent, appear to be correlated with the deterrent effect of the extractive upon the growth of fungi in the test blocks and on the Protozoa in the termite's digestive tract. The wide range of the total death rate, namely, 15 to 94 per cent, is clearly correlated with the variability in the amount of the extractive in our blocks. With a large amount of extractive the death rate was uniformly high. There were only two exceptions to this correlation in the 35 blocks.

The bore in the test blocks used by us was filled with water to moisten the walls, the water removed, and the surfaces dusted with finely powdered termite pellets from the burrows of the colonies from which the termites came, three to seven days before the termites were placed in the test blocks. Such pellets have been reported by Miss Hendee (chap. 9) to yield abundant cultures of the fungi associated with the termites. There is some lag between this seeding of the test samples with fungus spores and the establishment of the normal amount of growth of fungi in the wall of the artificial burrow. During this period migration and cannibalism would be favored in the newly established test groups. In any future use of our standard test method it would be desirable to prepare the test blocks prior to use by seeding them with powdered pellets and keeping the bore corked for several days before use. *Trichoderma lignorum* produces spores in cultures in seven days. Sporulation of the fungi favors its rapid spread in the newly formed burrows. It is probable that a seeding period of seven to ten days would prepare the test blocks with a suitable fungus infestation.

A STANDARDIZED BIOLOGICAL METHOD FOR TESTING RELATIVE RESISTIVITY OF WOOD SAMPLES TO TERMITE ATTACK

Development of method.—In the earlier work of the Committee the test blocks used were 2 inches × 2 inches × 5 inches, with a ⅜-inch hole bored to a depth of 2 inches at one end. Fifteen nymphs of the dry-wood termite, *Kalotermes minor*, were used in each block. The opening of the bore was closed with a cork or glass bottle. Several blocks of several species of wood were placed flat on one side adjoining each other in a humid, dark test room. The movement of the termites across from one block to another disclosed the weakness of this method of obtaining the measure of excavation in each block by the termites originally installed.

The next step was the separation of each block so that the termites could excavate only the one block in which they were installed. At the end of 60 days the blocks were removed. In blocks of wood having a volatile odor, such as Port Orford cedar, a large number of termites were dead. The stupefying effect of the volatile odor did not permit the termites to bore out and get air. Another difficulty was encountered in measuring the excavations in each block. The blocks were split lengthwise and the length of runways was computed in terms of a predetermined average diameter of 1.5 mm. Measurement of several nymphs of the size used showed the head to be of an average width of 1.5 mm. The excavations were in one of three forms: shallow surface workings, tunnels, or irregular cavities. The application of units of linear dimension to such irregular workings was found not to be consistent as between two investigators, and therefore to involve too large a factor of estimation. Several blocks which had been measured in this manner were measured later with mercury in a vacuum chamber and the results did not harmonize in any consistent manner with the volume computed from linear measurements.

It was later decided to reduce the size of the test block, increase the number of termites in each block, and measure the excavations by displacement with mercury. Therefore, the size of each block was reduced to one-fourth that used in the earlier investigations. Instead of 15 termites, 100 were placed in each block. The resulting excavations were, of course, concentrated within a small area of wood. Measurement of all burrows in the block by mercury displacement under pressure did not prove possible. It was observed that the flow of mercury into small tunnels was halted by the enclosed air. Blocks were therefore placed in a vacuum chamber and the bore and the excavations were filled from a burette with mercury, and the volume excavated measured on a burette. This method of measuring proved very satisfactory, as shown by repeated measurements of the same termite-riddled block, and as may be noted in the consistent results obtained in blocks from the same board.

Selection and care of termites.—Care was taken to install only healthy, active, uninjured nymphs from 0.6 cm. (¼ inch) to 1.0 cm. (⅜ inch) long. Reproductive nymphs with wing pads were rigidly excluded. The termites were handled with a small camel's hair brush. When counting and transferring them they were laid on sheets of cellophane. The termites were allowed to move slowly into the opening of the block by inserting a funnel-shaped sheet of cellophane in the opening and tilting the block and cellophane, thus permitting installation without injury to the insects.

Termites were secured from discarded pole tops of round poles of Port Orford cedar, western red cedar, and redwood in southern California. *Termites from separate pole tops were placed in separate containers.* Five different lots of termites, obtained on as many days, were used. Five to seven days elapsed before installing in the test blocks. Termites from each lot were installed in each of the principal species of wood tested. In all, 6,300 termites were installed in the wood blocks of the heartwood of Douglas fir, Ponderosa pine, and redwood.

Preparation of sample wood blocks.—Each test block measured 1 inch × 1 inch × 4½ inches. A hole ⅜ inch in diameter and 4⅛ inches long was accurately machine-bored at one end. The inner surface of the bore was smoothed by sanding. At the open end of each block in the test a thin coverglass 1 inch square, on which a square of black paper was laid, was held in place by a rubber band. The glass did not shut off the air supply entirely. The black paper permitted the bore in each block to remain in darkness when the room was illuminated.

In addition to the test blocks left undisturbed for 60 days, bi-weekly observation blocks were installed for watching the progress of the tests in each species of wood. These were split test blocks, the two halves being held in place by a rubber band. Four blocks each of Douglas fir, Ponderosa pine, and redwood heartwood, and Ponderosa pine sapwood, from seasoned commercial stock, were used for these observations. One block of each wood was examined at the end of the first two-week period after the test was started to check on the progress of the test. On each succeeding week an additional block was examined with the ones previously opened until at the end of the test all four blocks in each wood had been opened bi-weekly. One half-block sawn lengthwise tangential to the bore was installed for each major species of wood in the test for daily observation. The opened bore in the block was faced with glass held in place by a rubber band.

Control of temperature and humidity.—Each block of wood was placed on end in a separate glass refrigerator dish in the test room, in which there were no windows. The temperature was maintained at 25° C., and the humidity at 90 per cent. The test blocks, other than the observation blocks, remained undisturbed in a vertical position in the glass dishes for 60 days, at the close of which the termites were removed, counted, and preserved. Dead termites in the dishes were removed and recorded daily.

Measurement of excavations made by the termites.—Each test block was placed in a 500 cc. wide-mouthed bottle. A square of plate glass, in the center of which a 2 mm. hole had been bored, was placed over the open end of the bore in the block. All test blocks had been excavated by the termites with shallow channels under the coverglass on the end surface. The plate glass over the bore and these burrows reduced the meniscus above them. Under the plate glass the meniscus did not exceed 0.004 cc. A two-holed rubber stopper fitted the opening of the bottle. A glass tube connected by rubber tubing to the vacuum pipe was inserted in one hole; another glass tube connected by rubber tubing with a 25 cc. burette directly above was run through the other hole. One end of this glass tube was placed in the hole of the plate glass. Negative pressure of 25 inches of mercury, or slightly less than an atmosphere, was turned on and the mercury allowed to fill completely the excavations in the block. The burette was graduated in tenths of a cubic centimeter. Where termites had bored to the outside of a block the exit hole was sealed on the exterior with a strongly adhesive tape.

Unused blocks of each species of wood, which had lain in the test room throughout the test, were placed in the vacuum chamber and the machined bore of each was measured. The average measurement for the bores in each species of wood was subtracted from the measured excavation in each test block for the same species, in order to arrive at the figure for the amount of wood excavated by the termites in each test block. All blocks were stored in the laboratory and dried at ordinary room temperature until the measurement of the machined bore was constant. All blocks were measured at approximately the same temperature.

APPLICATION OF THE STANDARDIZED BIOLOGICAL TESTING METHOD TO UNTREATED COMMERCIAL WOODS

Test blocks were used of the heartwood of commercial species, including Douglas fir, black gum, Ponderosa pine, red oak, redwood, southern yellow pine, white oak, and red lauaan from the Philippine Islands. As a base line for common reference the sapwood of Ponderosa pine from one board was used. Experience has shown that sapwood generally is more susceptible than heartwood to attack by termites.

One test block was sawn from each of eleven boards of Douglas fir, eleven of Ponderosa pine, and twenty of redwood. From one of the boards in each species seven additional contiguous blocks were sawn and tested to ascertain if the method of testing would give consistent results within a supposedly uniform sample.

The tests were each continued for 60 days within the period November 9, 1932 to January 18, 1933. In nature this period normally falls within that of the winter minimum temperatures. At Los Angeles, near which the termites were collected, the average mean monthly temperatures for the last fifty-five years for November, December, and January were 61.6°, 56.7°, and 55.1°F., respectively.

It is therefore probable that the termites used in these tests were at the minimum of activity in so far as this is established in the annual cycle of feeding and reproducing. The degree to which exposure in our tests to abnormally higher temperatures (90°) at this season accelerated the termites' normal seasonal activity during the tests is not known. Evidence that there is a seasonal cycle of termite activity rests on general observations on laboratory

TABLE 41

RESULTS OF STANDARDIZED BIOLOGICAL METHOD OF TESTING WOOD

Tests continued 60 days within November 9, 1932 and January 18, 1933

Block No.	Excavations by termites	No. (=%) of original 100 termites alive at end of 60 days	Wood				
			Specific gravity	Annual rings per inch	Per cent of summer wood	Per cent extractive‡, based on amount of extractive compared with the dry weight of the wood	
						Ether-soluble	Hot-water-soluble
1	*2*	*3*	*4*	*5*	*6*	*7*	*8*
Ponderosa pine sapwood, each block from same board							
B1	3.1	82					
B2	3.5	82					
B3	3.8	94					
B4	4.5	95	31	13	15	2.97	....
B5	4.6	90					
B6	4.7	89	142 resin ducts per square inch				
B7	4.8	83					
Total	29.0	615					
Average	4.1	88					
Ponderosa pine heartwood, each block from a different board							
1PP0	0.6	59	38	18	20	2.93	....
2PP	0.8	39	....	18	16	....	....
3PP	0.8	56	....	27	24	....	....
4PP	1.1	72	....	17	10	....	....
5PP	1.2	65	....	16	14	3.22	....
6PP	2.0	86	....	22	20	....	....
7PP	2.8	94	....	7	24	....	....
8PP	3.5	86	....	10	24	....	....
9PP	3.8	77	....	11	27	....	....
10PP	4.1	98	....	13	36	....	....
11PP	4.7	78	....	7	27	0.63	....
Total	26.0	810	....	....	....	....	....
Average	2.4	73	....	....	....	....	....
Ponderosa pine heartwood, each block from same board as 1PP0							
1PP1	0.4	47	....	....	....	....	....
1PP2	0.4	34	....	....	....	....	....
1PP3	0.5	53	....	....	....	....	....
1PP4	0.5	53	....	....	....	....	....
1PP5	0.5	51	....	....	....	....	....
1PP6	0.6	53	....	....	....	....	....
1PP7	0.7	59	....	....	....	....	....
Total	3.6	350	....	....	....	....	....
Average	.5	50	....	....	....	....	....

‡ Determinations made by the Forest Products Laboratory, Forest Service, U. S. Department of Agriculture, Madison, Wisconsin.

TABLE 41—*(Continued)*

Block No.	Excavations by termites	No. (=%) of original 100 termites alive at end of 60 days	Wood				
			Specific gravity	Annual rings per inch	Per cent of summer wood	Per cent extractive‡, based on amount of extractive compared with the dry weight of the wood	
						Ether-soluble	Hot-water-soluble
1	*2*	*3*	*4*	*5*	*6*	*7*	*8*
Ponderosa pine heartwood, each block from same board as 8PP0. Tests made February 17 to April 17, 1933							
8PP1	3.8	74	....	....	....	....	....
8PP2	3.8	75	....	....	....	....	....
8PP3	4.0	87	....	....	....	....	....
8PP4	4.1	78	....	....	....	....	....
8PP5	4.3	88	....	....	....	....	....
Total	20.0	402	....	....	....	....	....
Average	4.0	80.4	....	....	....	....	....
Ponderosa pine sapwood, each block from same board as B1-B7. Tests made February 17 to April 17, 1933							
B26	6.5	89	....	....	....	....	....
B16	4.9*	53†	....	....	....	....	....
B15	4.7*	79†	....	....	....	....	....
Total	16.1	221	....	....	....	....	....
Average	5.37	73.6	....	....	....	....	....
Douglas fir heartwood, each block from a different board							
1F	2.7	90	....	13	38	1.2	....
2F	2.7	85	....	48	40	....	....
3F	2.8	86	....	15	22	....	....
4F	2.9	89	....	20	42	....	....
5F	3.2	82	....	18	28	....	....
6F0	3.3	98	42	20	29	0.73	....
7F	3.3	80	....	24	36	....	....
8F	3.5	71	....	7	25	....	....
9F	3.6	87	....	12	34	....	....
10F	3.7	89	....	15	34	....	....
11F	4.4	80	....	6	25	0.59	....
Total	36.1	937	....	....	....	....	....
Average	3.3	85	....	....	....	....	....

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* Excavations at end of 146 days: B16, 12.0 cc.; B15, 11.6 cc. Excavations at end of 60 days prorated from these figures.

† Number alive at end of 146 days from November 22, 1932 to April 17, 1933.

‡ Determinations made by the Forest Products Laboratory, Forest Service, U. S. Department of Agriculture, Madison, Wisconsin.

TABLE 41—*(Continued)*

Block No.	Excavations by termites	No. (=%) of original 100 termites alive at end of 60 days	Wood				
			Specific gravity	Annual rings per inch	Per cent of summer wood	Per cent extractive‡, based on amount of extractive compared with the dry weight of the wood	
						Ether-soluble	Hot-water-soluble
1	*2*	*3*	*4*	*5*	*6*	*7*	*8*
Douglas fir heartwood, each block from same board as 6F0							
6F1	3.3	92	....	....	....	....	....
6F2	3.3	96	....	....	....	....	....
6F3	3.4	88	....	....	....	....	....
6F4	3.5	98	....	....	....	....	....
6F5	3.5	99	....	....	....	....	....
6F6	3.5	98	....	....	....	....	....
6F7	3.8	94	....	....	....	....	....
Total	24.3	665	....	....	....	....	....
Average	3.5	95	....	....	....	....	....
Redwood heartwood, each block from a different board							
1R	0.3	14	....	68	44	....	13.8
2R	0.5	50	....	22	30	....	....
3R	0.5	33	....	13	19	....	....
4R	0.6	29	....	46	37	....	....
5R	0.6	15	....	37	40	....	....
6R	0.8	44	....	45	32	....	....
7R0	0.9	26	31	61	20	....	14.8
8R	1.1	69	....	9	14	....	....
9R	1.2	54	....	23	20	....	....
10R	1.2	46	....	30	42	....	....
11R	2.6	51	....	6	10	....	9.65
Total	10.3	431	....	....	....	....	....
Average	.9	39	....	....	....	....	....
Redwood heartwood, each block from same board as 7R0							
7R1	0.7	38	....	....	....	....	....
7R2	0.8	30	....	....	....	....	....
7R3	0.9	46	....	....	....	....	....
7R4	1.0	51	....	....	....	....	....
7R5	1.1	55	....	....	....	....	....
7R6	1.2	51	....	....	....	....	....
7R7	1.2	42	....	....	....	....	....
Total	6.9	313	....	....	....	....	....
Average	1.0	45	....	....	....	....	....

‡ Determinations made by the Forest Products Laboratory, Forest Service, U. S. Department of Agriculture, Madison, Wisconsin.

TABLE 41—*(Concluded)*

Block No.	Excavations by termites	No. (=%) of original 100 termites alive at end of 60 days	Wood				
			Specific gravity	Annual rings per inch	Per cent of summer wood	Per cent extractive‡, based on amount of extractive compared with the dry weight of the wood	
						Ether-soluble	Hot-water-soluble
1	*2*	*3*	*4*	*5*	*6*	*7*	*8*
Redwood compression butt heartwood, each block from a different log							
RC1	2.2	85	....	15	40	....	8.08
RC2	3.0	84	....	17	40	....	8.23
RC3	2.5	77	....	13	37	....	8.50
Redwood sinker heartwood, each block from a different log							
RS1	0.6	17	....	37	16	....	21.95
RS2	0.7	24	....	37	20	....	16.85
RS3	0.2	47	....	37	20	....	24.30
Redwood heartwood, structural grade, each block from a different log							
RST1	1.5	39	....	20	30	....	11.1
RST2	1.4	57	....	15	26	....	12.6
RST3	1.9	69	....	16	28	....	9.2
White oak heartwood, each block from the same board							
WO1	1.3	81	....	....	....	....	....
WO2	1.2	82	....	24	....	....	7.1
WO3	1.3	70	....	....	....	....	....
Black gum heartwood							
G1	3.0	88	....	....	....	....	....
Eastern white pine heartwood							
WP1	2.5	86	....	22	25	....	....
Red lauan heartwood, each block from the same board							
L1	2.8	60	....	....	....	....	....
L2	2.9	49	....	....	....	....	....
Red oak heartwood							
O1	3.1	93	....	11	....	....	....
Southern yellow pine heartwood							
SP1	1.8	87	....	....	....	....	....

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‡ Determinations made by the Forest Products Laboratory, Forest Service, U. S. Department of Agriculture, Madison, Wisconsin.

colonies and on tests made from February 17 to April 17, 1933 on one of the same blocks, 8PP (Table 41), as in the midwinter tests. These tests indicated a much higher rate of activity in feeding in this warmer season than that detected under strictly comparable conditions in the earlier tests in the colder season but at the same test room temperatures. As shown in Table 41, the excavations in the heartwood of Ponderosa pine block 8PP were 3.5 in midwinter and 4.0 in early spring, an increase of 14 per cent. In seven test blocks of Ponderosa pine sapwood tested in midwinter the average excavation was (3.1–4.8) 4.1 cu. cm., while in three different blocks tested in the spring the average amount was (4.7–6.5) 5.37 cu. cm., an increase of 31 per cent.

In the light of these seasonal differences and of the observed facts of the seasonal activity of insects, it is probable that the warm temperature (90°) of our test room in the midwinter season did not increase the activity of the termites in the test blocks to the level of that of spring or summer. The vol-

TABLE 42

RANGE OF RELATIVE TERMITE RESISTANCE WITHIN AND BETWEEN SAMPLES FROM DIFFERENT SPECIES OF WOOD

Kind of wood	Number of tests	Volume of wood excavated, cc.	Per cent resistance compared with average for Ponderosa pine sapwood	Per cent extractive,* based on amount of extractive compared with the dry weight of the wood	
				Ether-soluble	Hot-water-soluble
Ponderosa pine sapwood	7	4.1 (3.1 to 4.8)	0.0	2.97	......
Douglas fir heartwood	1	2.7	34.2	1.2	......
	7	3.5 (3.3 to 3.8	14.7 (19.6 to 17.3)	0.73	......
	1	4.4	0.0	0.59	......
Ponderosa pine heartwood	1	0.6	85.4	2.93	......
	7	0.5 (0.4 to 0.7)	87.8 (90.2 to 82.9)	3.22	......
	1	4.7	0.0	0.63	......
Redwood heartwood	1	0.3	92.7	......	13.8
	7	1.0 (0.7 to 1.2)	75.6 (82.9 to 71.7)	......	14.8
	1	2.6	36.6	......	9.65
heartwood from sinker logs	1	0.6	85.4	......	21.95
	1	0.7	82.9	......	16.82
	1	0.2	95.1	......	24.3
heartwood, structural grade	1	1.5	63.4	......	11.1
	1	1.4	65.9	......	12.6
	1	1.9	53.7	......	9.2
compression-heartwood from butt logs	1	2.2	46.4	......	8.68
	1	3.0	26.0	......	8.23
	1	2.5	39.0	......	8.5
White oak heartwood	3	1.26 (1.2 to 1.3)	69.3 (70.7 to 68.3)	......	7.1

* Determinations made by the Forest Products Laboratory, Forest Service, U. S. Department of Agriculture, Madison, Wisconsin.

umes of excavation reported in our tests do not represent those of summer activity, but only those of winter activity, with a small increment due to the warmth of the room in which the tests were made.

TABLE 43

DATA ON BEHAVIOR OF TERMITES IN DIFFERENT SPECIES OF WOOD TESTED

Species of wood	Number of samples tested	Number of different boards from which blocks were sawn	Total number of termites installed in the tests of the wood	Number of termites dead at end of 60 days		Number of termites with wing pads at end of 60 days	Number of holes bored by termites from the machined bore to outside of blocks	
				Total	Average and range (=%) in blocks		Total	Average and range (=%) in blocks
Ponderosa pine sapwood	7	1	700	85	12 (5 to 18)	13	100	14.3 (10 to 19)
Douglas fir heartwood	18	11	1,800	198	11 (1 to 29)	16	177	9.4 (4 to 17)
Ponderosa pine heartwood	18	11	1,800	540	30 (2 to 66)	11	146	8.2 (0 to 17)
Redwood heartwood	27	20	2,700	1,457	54 (15 to 86)	12	224	8.3 (0 to 19)
White oak heartwood	3	1	300	67	22 (18 to 30)	3	21	7.0 (4 to 11)

EXTRACTIVES IN WOOD IN RELATION TO TERMITE ATTACK

The tests show a general trend of differences in the relative termite resistance both among the different species of wood and within selected samples of the same species. Redwood was high, Ponderosa pine and Douglas fir lower in resistivity among those species most extensively tested. The tests indicate a varying amplitude of range in termite resistance within each species and considerable uniformity within a single board. Our tests show that the capacity of wood to resist termite attack was in general the greatest in those blocks having a high percentage of extractive, and the lowest in those blocks containing the low percentages. The figures in Tables 41–42 indicate in percentages the loss of weight in wood samples after extraction.

The extractive content and specific gravity determinations of woods in Tables 41–42 were made at the Forest Products Laboratory of the U. S. Department of Agriculture, Forest Service. The extractives for heartwood are those which have been found largely to explain the relative resistance to decay of several woods (Hawley, Fleck, and Richards, 1924; Sherrard and Kurth, 1933*a*). The extractive in sapwood has been found to be relatively less toxic, or possibly more favorable, to fungus than the corresponding heartwood extractive (Hawley, Fleck, and Richards, 1924; Gäumann, 1930; Knuchel, 1930; Sherrard and Kurth, 1933*a*). Thus, the extractive in the sapwood of Ponderosa pine (Table 42), while about the same *in percentage* as that for Block 1 of the heartwood of Ponderosa pine (Table 42), does not make the relative resistance to decay the same in these two specimens, possibly because of qualitative differences in the extractive.

The amount of extractive in any species which results in its durability is not the same for all species. The hot-water-soluble extract in redwood has been found to range from 5.45 to 28.23 per cent (chap. 42) of the dry weight of the wood. Schorger (1926) gives the following percentages of the extractives from four samples each of Ponderosa pine and Douglas fir:

Ponderosa pine:		
Cold-water-soluble	(2.97–5.58)	4.08 per cent
Hot-water-soluble	(3.40–6.33)	5.07 per cent
Ether-soluble	(6.48–9.63)	8.02 per cent
Douglas fir:		
Cold-water-soluble	(2.94–4.25)	3.54 per cent
Hot-water-soluble	(6.07–6.96)	6.50 per cent
Ether-soluble	(0.94–1.11)	1.02 per cent

These tests suggest the advisability, when purchasing naturally resistant wood, of requiring, as is the practice in the case of treated woods, that it meet definite specifications, involving laboratory tests of samples, which will insure that it contains the proper percentage of effective extractives.

Some woods, such as Port Orford cedar, contain a considerable part of the extractive in the form of volatile oils which afford the principal source of the resistance of these woods to termites. In nature, termites will attack such wood from which this oil has been evaporated by weathering. The removal of the oil in laboratory experiment by continuous heating also renders the wood susceptible to attack. The volatile oil may be thus decreased to a point at which it does not offer any further termite deterrence. How far the protective extractives in other woods are volatile is as yet inadequately known. Field observations suggest that prolonged weathering makes for susceptibility to termite attack, but it has not been possible in such observations to distinguish between the effects of weathering on the one hand, and the degree of exposure to termite infestation, on the other.

It has been noted by us that some very resinous pieces of heartwood from Ponderosa pine, a species which is usually palatable, are less palatable to termites than heartwood from that species which is low in resin content. Hunt (1928*b*) indicates that woods of these two types react in like contrasts to decay. "The natural preservatives stored in the heartwood may be present in larger amounts in some trees than in others of the same species. Wide differences in this respect may be found even in different parts of a single log, with resulting differences in decay resistance. In the pines and Douglas fir occasional pieces are very resinous or pitchy. Wood thus saturated with pitch or resin is exceptionally resistant to decay and gives very long life in contact with the ground or in other places where conditions favor decay."

All of the samples of Douglas fir heartwood tested by us contained relatively low percentages of extractive as compared with other species, and our findings therefore fail to record the full range in variability in resistance of this species of wood to termites. However, in the samples tested by us there is a direct correlation between amount of extract and volume of wood excavated by the termites.

The exact method by which the extractive of redwood and other woods acts so as to deter or prevent attack by termites has not been analyzed. It is not simple and direct, but probably affects the life of the termites in several ways. The extractive contains something which inhibits the growth of the wood-destroying fungus, *Fomes annosus,* and which increases in effect with an increase of the amount in the wood, according to Sherrard and Kurth (1930*a*). These authors (1930*b*) have also isolated two chemical substances, sequoyin and isosequein, which have phenolic properties. Their toxicities are as yet unknown.

Termites leave test blocks of redwood in much greater numbers (Table 40) than other woods tested. There is thus a repellent action which adds to the resistivity of at least certain kinds of redwood, evidently (Table 42) those with the larger amounts of extractive. There was a higher death rate of termites (Table 41) in redwood test blocks (54 per cent) than in Ponderosa pine (27 per cent) or in fir (11 per cent).

The cause of the death of the termites is unknown. It might be due to a lack of the necessary amount of fungi in their diet, or a direct toxic effect of the extractive or of some definite substance contained in it, or to the poisoning of the Protozoa in the digestive tract of the termite, resulting in a cessation of their contribution to the life of the termites. Cleveland (1924) has shown that when these Protozoa have been killed by exposing the termites to oxygen, the termites die soon thereafter. Two or more of these factors may combine to kill the termites.

Some light is thrown on the matter by the condition of the Protozoa in the digestive tract of the termites used in the redwood test blocks. The termites surviving in the blocks at the end of sixty days were killed in alcohol and the contents of the digestive tract of a representative number, generally ten to twenty-five, were examined under the microscope. A rough quantitative estimate of the numbers of Protozoa present was made and the results are incorporated in Table 44.

The actual test blocks which were exposed to termite attack were analyzed for the hot-water extractive by the Forest Products Laboratory of the U. S. Department of Agriculture. In the table the entries are arranged in the order of the increasing amounts of this extractive. The table also includes our records of the annual rings per inch and the percentages of summer wood, together with the results of exposure to the attack of termites, expressed in cubic centimeters of wood excavated in each block.

The effect of the extractive content of the wood of each block upon the termites confined to each block is exhibited by the number of termites leaving the block and found dead in the dish containing the test block, and by the death rate among the original 100 termites placed in the block. The former is a rough measure of the repellent action of the individual test block against termite invasion, and the latter is a more accurate measure of the actual toxicity of the extractive of the particular block to the termites feeding upon it.

An additional test of the toxicity of the extractives of the various test blocks is presented by the estimated percentages of Protozoa remaining in the digestive tract after 60 days' exposure to the diet of the wood of the test block in which the host termites were confined. From 10 to 25 (in one case only 3 were available) termites were examined and the relative numbers of the representative Protozoa present, as compared with a normal number observed in wild colonies, were recorded. Table 44 records the average and range of such estimates. The range is very wide, but generally only a few individuals retain or approach the normal condition. Such normal individuals probably include the cannibals who have been feeding upon termites rather than on the wood. It should be remembered the Protozoa actually ingest and presumably digest the wood which the termite is eating, and are therefore exposed directly to the effect of the extractive contained therein.

TABLE 44

EFFECT OF REDWOOD EXTRACTIVE ON PROTOZOA IN INTESTINE OF TERMITES

Block No. (see Table 41)	Excavations in cu. cm.	Percentages of termites dead at end of 60 days	Annual rings per inch	Per cent of summer wood	Extractive in per cent of dry weight	Dead termites in dish	Number of termites examined	Estimated percentage of Protozoa dead	
								Average per cent	Range in per cent
RC 2	3.0	16	17	40	8.23	0	25	45.0	0-90
RC 1	2.2	15	15	40	8.68	0	25	14.0	0-90
RST 3	1.9	31	16	28	9.2	0	25	11.0	0-90
11 R	2.6	40	6	10	9.65	6	25	11.0	0-90
RST 1	1.5	61	20	30	11.1	0	25	50.0	0-90
RST 2	1.4	43	15	26	12.6	7	10	92.0	90-100
1 R	0.3	86	68	44	13.8	21	10	85.0	50-95
7 R 0	0.9	74	61	20	14.8	39	20	75.0	20-95
RS 2	0.7	76	37	20	16.85	5	25	90.0	15-100
RS 1	0.6	83	37	16	21.95	4	10	88.0	50-95
RS 3	0.2	53	37	20	24.30	1	15	85.0	50-95
Extractives of other woods									
11 F	4.4	20	6	25	0.59	0	25	1.2	0-15
11 PP	4.7	22	7	27	0.63	0	25	60.0	0-100
1 F	2.7	10	13	38	1.2	0	25	26.0	0-90
1 PP 0	0.6	41	18	20	2.93	9	3	93.0	90-95
5 PP	1.2	35	16	14	3.22	1	25	48.0	0-90

Under normal conditions, where termites are living in wood of their own selection, the Protozoa in the gut ingest the particles of wood very completely and there is very little free wood unutilized by them left floating in the intestinal fluid. Observations on the Protozoa of termites forced to feed upon wood with a large amount of extractive, as in redwood and Ponderosa pine, reveal the fact that much of finely chewed-up wood is unappropriated even when the Protozoa have not as yet been greatly reduced in numbers. Some of the wood is, however, ingested, and in the higher levels of extractive, above about 12 per cent, the death rate both of the Protozoa and of their termite hosts is accelerated, with the ultimate complete extinction of the Protozoa and a sufficient reduction of the termites in 60 days to threaten the extinction of the colony.

Table 44 very clearly leads to the following conclusions:

(1) Large amounts of extractive are directly correlated with a high death rate of termites, lessened excavation, more termites leaving the block, and heavier destruction of the Protozoa.

(2 The smaller amounts of extractive are associated with lower death rate, more excavation, less migration, and little if any destruction of the Protozoa.

(3) Redwood containing hot-water extractive in amounts above about 12 per cent by dry weight of the wood is toxic to the Protozoa in 60 days or less.

(4) Redwood containing hot-water extractive in amounts below about 12 per cent is not lethal to the Protozoa in 60 days.

(5) These differences in the amounts of the extractive, or of some definite chemical substance or substances of the wood and in the extractive, may account for the resistivity of redwood to termite attack when the extractive is abundant, and for the failure to resist when it is not abundant. The line of separation between these two conditions probably lies near 12 per cent.

(6) Additional investigation is needed to determine the chemical nature of the lethal substance (or substances), to find its effective lethal concentration, and to determine its distribution in the tree. The possibility that the seasonal cycle of growth of the tree may affect the amount (Gäumann, 1930) and the distribution of the extractive and its contained lethal substance, and differentially determine both the amount and distribution of those substances, favorable as well as unfavorable to termites, should be considered in such investigations.

(7) The quantitative determination of the amount of the lethal substance and of its distribution in the tree may afford a satisfactory basis for the grading of second growth and virgin redwood for commercial purposes and industrial uses.

Our investigations have thus resulted in the establishment of a standardized biological method for the determination of relative termite resistivity of natural and of chemically treated woods. Its application to natural woods gives coherent and consistent results of fair uniformity with contiguous samples from the same board. Different species of commercial woods show differences in resistivity. The amplitude of variation in resistivity within the species varies for the different species. This is notably the case in redwood, in which our test blocks were most numerous. The variations in termite resistivity show a fairly direct correlation with the amount of the extractive. The hot-water-soluble extractive of redwood shows wide variations in amount which are inversely correlated with the volume of excavations of termites, and directly correlated with the death of Protozoa in the termite gut. Samples of redwood with highest extractive have least excavation. Samples with extractive over about 12 per cent by weight are lethal to the Protozoa of the termite gut and result in the death of from 43 to 86 per cent of the termites in 60 days.

Presumably, wood retaining not less than 12 per cent of extractive is adequately termite-resistant when and so long as it contains this amount of the hot-water-soluble extractive.

The data from our tests on the death rate of Protozoa suggest a typical biological curve with the major inflection at about 12 per cent of the extractive. Our tests are not numerous and more tests are needed to confirm and accurately outline the curve. The precise toxic constituent of the extractive, its relation to the total hot-water-soluble substances, and its constancy at and near the lethal amount (presumably about 12 per cent) of total hot-water-soluble extractives should be the subject of further investigation.

APPLICATION OF THE STANDARDIZED BIOLOGICAL TESTING METHOD TO TOXICITY TESTS OF TREATED WOOD

Tests were made to determine the toxic value of wood preservatives in various concentrations and amounts applied to wood. The method of testing included the installation of fifteen termites in a hole bored in each wood block, of standard size and pattern, and placing the blocks in a test room in which the temperature and humidity were controlled. The blocks had been recently treated, except as noted, and not exposed to service conditions out-of-doors. Untreated wood block controls were also installed. The small number of termites was used to reduce the period of survival of termites based on cannibalism.

Description of the preservatives will be found in chapter 34. The size and kind of termites used were the same as those for the untreated wood tests, and the conditions were the same as for the untreated wood tests. Blocks were treated by the cooperating companies and figures for absorption of preservative were furnished by them. A summary of results of the tests of certain preservatives and chemicals used in preservatives follows.

Reilly Transparent Penetrating Creosote.—Tests were made with the cooperation of the Reilly Tar and Chemical Corporation. This substance is a proprietary preservative manufactured by them (chap. 34). The makers state that Reilly Transparent Penetrating Creosote as offered to the public contains 25 per cent by weight of refined coal-tar creosote. Tests were made by us of the commercial product and also of a 12 per cent solution.

Termites did not feed upon blocks which were pressure-treated with a 12 or 25 per cent solution by weight, even when the odor was eliminated from the treated wood. The odor from the treatment was eliminated by drying the blocks up to two months over a radiator. The volatile part of the chemical was thus largely eliminated and was not operative in effecting a satisfactory kill of the termites.

The immersion treatments were not consistently effective in preventing the termites from feeding on blocks thus treated and in producing a kill of termites, due undoubtedly to insufficient absorption of preservative by this method of application.

TABLE 45

TESTS OF REILLY TRANSPARENT PENETRATING CREOSOTE AND OF SOLWAX

Preservative solution	Kind of treatment	Number of test samples	Number of termites used	Number of termites alive at end of tests		Absorption of preservative per cubic foot		Number of days to effect 80 per cent kill	Excavations by termites	
				Number	Per cent	Minimum	Maximum		Number of blocks attacked	Number of excavations
						pounds	*pounds*			
Reilly Transparent Penetrating Creosote	Pressure, 25% solution	42	615	7	1.1	7.0	22.0	15	0	0
	Pressure, 12% solution	28	405	4	0.98	7.1	19.7	17	0	0
	16-hour immersion, 25% solution	36	510	55	10.7	2.2	14.5[1]	35	4[3]	10 (1 to 4 per block)
	½-hour immersion, 25% solution	38	555	60	12.4	1.3	7.5[2]	47	9[4]	24 (2 to 5 per block)
Solowax	1-hour immersion	26	475	2	0.42	0.6	3.9	35	3	5
	Pressure (treated one year before testing)	4	60	2	3.3	8.5	16.7	15	0	0

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[1] Excavations by termites were not made in blocks containing more than 4.9 pounds of preservative per cubic foot.

[2] Excavations by termites were not made in blocks containing more than 3.4 pounds of perservative per cubic foot.

[3] The absorption of the preservative in the four blocks excavated by termites was 3.1, 3.5, 4.4, and 4.9 pounds per cubic foot, respectively.

[4] The absorption of the preservative in the nine blocks excavated by termites was 1.3, 1.5, 1.7, 1.8 1.8, 2.5, 2.5, 2.8, and 3.4 pounds per cubic foot, respectively.

This preservative has the advantage of a high degree of penetration by the pressure process. Blocks of Douglas fir, 4 inches x 4 inches x 24 inches, submitted to us by the manufacturers and said to have been pressure-treated, showed complete infiltration. This enhanced power of penetration over that of ordinary creosote will tend to meet the difficulties caused by the checking of creosote-treated timbers through the impregnated layer after impregnation. These checks, traversing the outer layer of impregnated wood, open up the untreated center to termite settlement and attack.

This material also quickly loses its odor and does not bleed when warmed. Wood treated by Reilly creosote is only very slightly colored by it and may be painted.

The residue left in the wood after the evaporation of the solvent is stated by the makers to be a high grade coal-tar creosote. Our laboratory tests have shown that this residue prevents termite attack under favorable conditions of temperature, moisture, and continuous control of an initially healthy group of termites. The poundages of the Reilly creosote tested (7 to 22 pounds of 12 and 25 per cent solutions per cubic foot) are comparable to those of commercial practice with ordinary creosotes. The actual amounts of refined undiluted creosote per cubic foot of wood remaining after evaporation of the solvent (0.84 to 5.5 pounds in the wood tested by us) are naturally reduced below those after impregnation by ordinary creosote, but the penetration and distribution are superior to those attainable in pressure treatment with ordinary creosotes. The amounts of creosote retained, even with the 12 per cent treatment, were sufficient to be lethal to termites in laboratory tests. The rate of death was high in the pressure-treated blocks.

This method of securing a greater depth of penetration of the creosote represents a direction of development in the wood-treating industry of seemingly great promise. Creosote thus applied gives promise of a better control of attacks by rot and termites, because of its retained toxicity, deeper penetration, and wider adaptability for use in dwellings, but it awaits the sanction of service tests.

Solwax.—Tests were made with the cooperation of the Republic Creosoting Company. This substance is a proprietary preservative manufactured by them (chap. 34).

Termites did not feed upon blocks which were pressure-treated with 8.5 pounds of solution per cubic foot. The rate of death of termites was high in these test blocks. The rate of kill in the immersed blocks was very irregular.

A summary of the kill of termites in these tests is given in Table 45.

In estimating the protective effect of immersion treatments note should be made of the fact that the blocks used were small (1 inch × 1 inch × 4½ inches), and that the area and volume of wood affected by the immersion were therefore relatively very great as compared with the area and volume affected by immersion as used in construction. It should also be noted that if termites once penetrate the thin shell of wood protected by immersion the deterrent effect of such treatment is permanently overcome. A normal colony in continuous contact with wood merely immersed in a chemical treatment but having other sources of food has a better opportunity to penetrate the protective coat than has a colony restricted solely to a diet of creosoted wood, since losses in death can be recouped, and the continuity of the attack maintained until the thin shell is penetrated.

TABLE 46

TESTS OF CHEMICAL PRESERVATIVES

Preservative solution	Approximate pounds dry salt per cubic foot of pressure-treated wood	Number of tests	Excavations by termites	Number of termites installed	Number of termites alive at end of 60-day test
0.5% Sodium silicofluoride	0.13	5	0	75	0
1% Sodium silicofluoride	0.29	5	0	75	0
1.5% Sodium silicofluoride	0.52	5	0	75	0
1% Zinc chloride 0.5% Sodium dichromate 0.25% Sodium silicofluoride	0.48 0.24 0.22	5	0	75	0
1% Zinc chloride 0.5% Sodium dichromate 0.5% Sodium silicofluoride	0.50 0.25 0.25	5	0	75	0
1% Zinc chloride 0.5% Sodium dichromate 1% Sodium silicofluoride	0.51 0.26 0.51	5	0	75	0
1% Zinc chloride 0.5% Chromic chloride 0.42% Zinc silicofluoride	0.40 0.20 0.17	5	0	75	0
1% Zinc chloride 0.5% Chromic chloride 0.82% Zinc silicofluoride	0.50 0.25 0.25	5	0	75	0
1% Zinc chloride 0.5% Chromic chloride 1.64% Zinc silicofluoride	0.50 0.25 0.83	5	0	75	0
0.42% Beta naphthol	0.001	5	0	75	0
0.375% Arsenate crystals	0.12	5	0.15 cc.	75	1
0.7% Sodium dichromate	0.24	5	1.67 cc.	75	28
0.75% Chromic chloride	0.25	5	3.08 cc.	75	50
0.75% Aniline hydrochloride	0.257	5	4.24 cc.	75	41
0.375% Tetrachlorophenol	0.07	5	0	75	0
0.75% Tetrachlorophenol	0.18	5	0	75	0
1.125% Tetrachlorophenol	0.29	5	0	75	0

The tests enumerated in Table 46 were made in cooperation with the Century Wood Preserving Company of Pittsburgh, Pennsylvania, on a number of chemicals used in wood preservatives (chaps. 33–35). The period of the tests was 60 days. For effectiveness of zinc chloride alone see pages 379–384.

The application of the Standardized Biological Testing Method to treated wood was used mainly to determine the rate and time of kill of the standard termite colony by the toxic substances introduced by several methods and in varying amounts. The records of the volumes excavated were not always made, since the amount in all cases was small and since the main objective was to determine whether or not material was sufficiently toxic to prevent any significant attack by the termites on the treated wood. For this purpose the value of the method lies in the adequate control of the biological conditions of the test, the insurance of an adequate laboratory test, and a uniform rating of the results.

The use of an 80 per cent kill of termites as significant of final extermination of the colony rests on observations of experimental laboratory tests. Any colony subjected to toxic material which reaches this level of depletion and continues in the same surroundings is doomed to early extinction. Cannibalism may continue the colony for a time, but even this fails soon. The 80 per cent kill is practically quite as reliable in tests of toxicity as a 100 per cent kill.

CHAPTER 42

I. DISTRIBUTION OF EXTRACTIVE IN REDWOOD

ITS RELATION TO DURABILITY[1]

BY

E. C. SHERRARD and E. F. KURTH

Hawley, Fleck, and Richards[2] have demonstrated that the relative resistancy to decay of various woods could be largely explained by the toxicity of their hot-water extracts. The material toxic to fungi in redwood is readily extracted with alcohol, hot water, and dilute alkalies, such as one per cent sodium hydroxide and sodium carbonate. Less extract is removed with cold water and with ether than with any of the foregoing solvents. An attempt is made in this paper to correlate the amount and location of the extractives in the tree with the durability of the wood from different parts of the trunk.

DISTRIBUTION OF EXTRACTIVE IN REDWOOD

Studies at the Forest Products Laboratory on virgin redwood have demonstrated a clearly defined variation in extractive content of the heartwood with height in tree and with position in cross section of the trunk. Similar studies on young, second-growth redwood have revealed that, although a corresponding variation in the extractive is usually perceptible, the tendency is toward a more uniform distribution. In virgin-growth trees the aqueous extractive is highest in the heartwood adjoining the sapwood of the butt and decreases toward the center of the cross section. In the outside heartwood there is a gradual decrease of extractive with increase in height of the tree; at the center it increases until near the top a point is reached at which the concentration is almost uniform throughout the cross section of the trunk. Both the cold-water extract and the hot-water extract show the same relative distribution throughout the trunk, although the values for the cold-water extract are of smaller magnitude. Wherever compression wood is encountered, the extractive content is abnormally low.

The average hot-water extractive content of seven second-growth redwood trees, varying in age from 45 to 64 years, was found for sapwood to be 3.2 per cent at the 1-foot height, 2.6 per cent at the 35-foot height, and 2.8 per cent at the top of the trunk; for heartwood the values 12.3, 10.1, and 11.2 per cent were obtained for the respective heights.

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[1] Reprinted by permission from *Industrial and Engineering Chemistry*, Vol. 25, Page 300, March, 1933. Part of a paper presented before the Division of Cellulose Chemistry at the 79th Meeting of the American Chemical Society, Atlanta, Ga., April 7 to 11, 1930.

[2] Hawley, L. F., Fleck, L. C., and Richards, C. H. *Ind. Eng. Chem.*, **16**, 699 (1924).

The distribution of extractive in virgin-growth redwood is represented graphically in figure 132. This graph presents the amounts of hot-water extractive throughout cross sections taken from six heights in a tree. The amount of extractive in sapwood as shown by the points at the extreme left is much smaller than in the heartwood immediately adjacent. The values for the 88-foot height of this tree are abnormal in that they are lower than the values for sections of the trunk above this level.

Toxicity of Redwood Extractive

The hot-water extracts from the heartwood of different parts of the redwood tree (the extractive distribution of which is given in fig. 132) were concentrated to the point where 3 cc. represented the extract from one gram of wood. Concentration beyond this caused a precipitation of the extractive in the extracts from those sections which had a high extractive content. Three different dilutions of these extracts were made with malt agar and inoculated with the wood-destroying fungus, *Fomes annosus*. The value of the toxicity of the extract was obtained by measuring at definite intervals the radial growth of the *Fomes annosus* .This growth subtracted from the normal growth of the organism on plain malt agar gave the retardation which, divided by the normal growth and multiplied by 100, gave the percentage retardation.

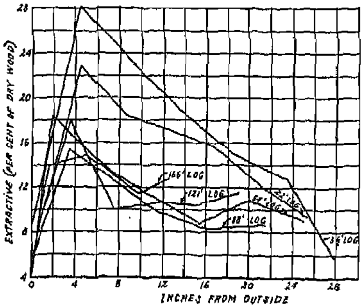


Fig. 132. Distribution of extractive in redwood. After Sherrard and Kurth (1933a, fig. 1).

The results of the toxicity tests are summarized in Table 47. The extracts obtained from the outside sections of the heartwood, which have a high extractive content, practically inhibited *Fomes annosus* in the concentrations used; the extracts obtained near the center of the trunk where the extractive content was low, did not completely inhibit the growth of the organism. Although these tests show the relative toxicity of the wood at about the time the tree was felled, they are not a conclusive measure of the relative durability. It is reasonable to assume, however, that the durability of redwood containing a large amount of extractive will be greater than redwood containing only a small quantity of extractives.

RELATIONSHIP OF DURABILITY TO EXTRACTIVE CONTENT

The foregoing toxicity tests were supplemented with tests of durability in culture tubes under favorable conditions for decay, and also in the soil under natural conditions. For this purpose, 1 inch × 1 inch × 1 foot specimens were cut from planks taken from different heights of the trunk of a redwood tree as shown in figure 133. The planks 65-SE-6B, 65-SE-6FG, and 65-SE-YZ were taken from the southeast quarter at heights 4 to 8, 24 to 32, and 100 to 108 feet, respectively, above the ground. One set of these specimens was exposed to the action of wood-destroying fungi, *Poria incrassata,* and two unidentified wood-rotting fungi in culture tubes. Another set was placed in the soil in an outdoor experimental plot at Madison, Wisconsin.

TABLE 47

RELATION OF TOXICITY TO HEARTWOOD EXTRACTIVE

Height in tree	Distance from center of trunk	Extractive content of wood	Retardation		
			50 cc. extract, 45 cc. agar	50 cc. extract, 35 cc. agar	50 cc. extract, 16 cc. agar
feet	*inches*	*per cent*	*per cent*	*per cent*	*per cent*
166.0	12.5	13.97	99	100	100
121.0	17.5	18.15	99	99	100
88.0	22.0	15.50	100	100	100
54.0	24.5	18.29	100	100	100
22.0	23.0	22.92	95	100	100
3.5	27.0	28.23	99	100	100
166.0	1.5	12.75	100	100	100
121.0	2.0	11.48	94	99	100
88.0	4.0	8.83	84	90	96
54.0	1.5	9.15	87	92	96
22.0	1.5	9.40	87	95	98
3.5	3.5	5.45	51	92	95

TABLE 48

RELATION OF LOSS IN WEIGHT, DUE TO DECAY, AND AMOUNT OF EXTRACTIVE IN WOOD

Samples nearest pith			Samples nearest sapwood		
Height in tree	Extractive content	Loss in weight	Height in tree	Extractive content	Loss in weight
feet	*per cent*	*per cent*	*feet*	*per cent*	*per cent*
4-8	9.24	4.12	4-8	18.04	3.36
24-32	8.74	9.48	24-32	13.15	4.85
100-108	8.47	8.45	100-108	8.87	6.86

The results of the culture tube tests are summarized in Table 48, which gives the extractive content and the loss in weight through decay for a period of 16 months. The values are the averages for the specimens taken from the pith side or from the sapwood side of the individual planks.

Of forty-eight specimens placed in the soil, sixteen showed decay after 40 months. Fifteen of the specimens showing decay came from the top or center of the trunk where the extractive content was lowest. Only one specimen came from a section of high extractive content. Although the outdoor service tests have not been of sufficient length to be conclusive, they do, however, substantiate the results of the foregoing toxicity and durability tests.

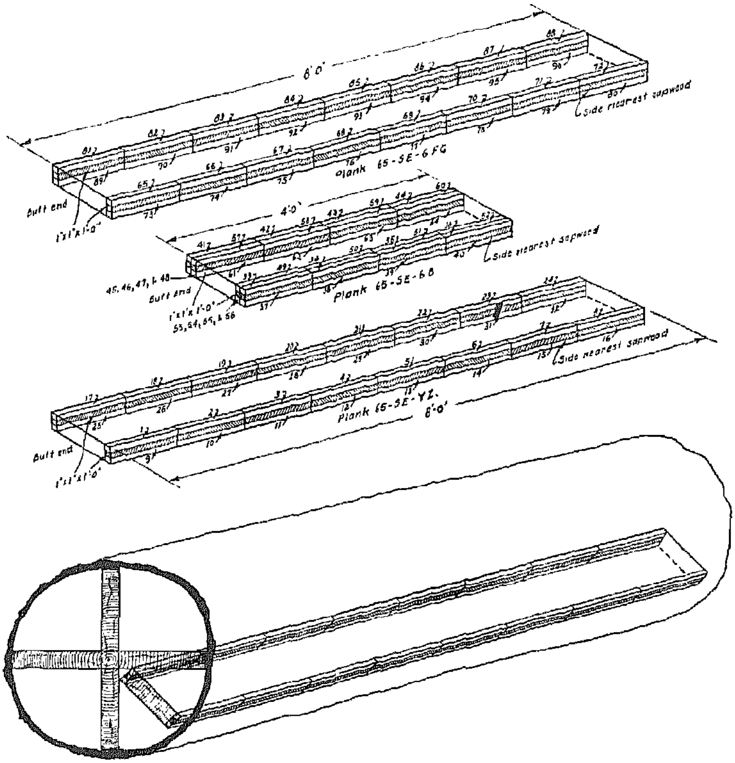


Fig. 133. Redwood specimens used for durability tests. After Sherrard and Kurth (1933*a*, fig. 2).

It appears, therefore, that the durability of redwood will vary with the extractive distribution; the most durable redwood should be the heartwood of the butt log nearest the sapwood, the susceptibility to decay increasing toward the pith of the tree and toward the top.

The toxicity of redwood extractive has not been ascribed to any one compound. Upon dry-distilling the alcohol or hot-water concentrates, a good yield of phenolic substance is obtained which inhibits the growth of *Fomes annosus* at a concentration of 0.05 to 0.1 per cent. It is, therefore, somewhat more toxic than phenol and about four times as toxic as zinc chloride.

The aqueous extractive in young, second-growth redwood trees is comparatively uniformly distributed throughout the heartwood of the trunk. In old, virgin-growth trees there is a decrease of extractive at the center of the trunk with decrease in height in the tree, and a large increase of extractive at the outer edge of the heartwood with decrease in height in the tree.

The durability of redwood is attributed to the nature of the extractive and varies wih the extractive distribution.

ACKNOWLEDGMENT

The toxicity tests were obtained with the cooperation of R. H. Baechler of the Forest Products Laboratory. Both the isolation of the fungi from rotted redwood heartwood and the culture-tube durability tests were made under the direction of C. A. Richards of the Division of Forest Pathology.

II. THE CRYSTALLINE COLORING COMPOUNDS IN REDWOOD EXTRACT[2]

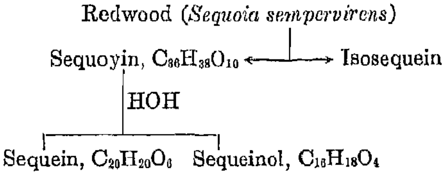
BY

E. C. SHERRARD and E. F. KURTH

Contribution from the Forest Products Laboratory,[1] Forest Service, U. S. Department of Agriculture

The heartwood of freshly cut green redwood is usually of a straw color. Soon after the surface is exposed to the atmosphere a red to brown discoloration develops. This paper describes the isolation and several properties of two crystalline coloring substances which, together with certain of their derivatives, may be responsible for the red and brown colors in seasoned redwood. In naming these compounds an attempt was made to conform as nearly as possible to the nomenclature used by Perkin and Everest[3] on coloring matter of similar nature.

The compounds and the relationship of a few derivatives are


Redwood (*Sequoia sempervirens*)
Sequoyin, $C_{36}H_{38}O_{10}$
Isosequein
HOH
Sequein, $C_{20}H_{20}O_6$
Sequeinol, $C_{16}H_{18}O_4$

One of the compounds, *sequoyin,* crystallizes when pure in white or pink flakes, melting at 214° (uncorr.). The other substance, *isosequein,* has been obtained from only two redwood specimens, but its presence is apparent in most redwood liquors. It crystallizes in clusters of red needles, melting sharply at 188°. Its isolation is made difficult by the presence of a relatively large amount of gums, tannins, phlobaphenes and other soluble material in redwood. All treatments that remove these impurities also remove the color compound.

Sequoyin appears to be best obtained by lixiviating green or seasoned redwood in the form of sawdust or chips with distilled water at room temperature. The product is concentrated to a thick sirup by distillation under reduced pressure. The distillate thus obtained is colorless and apparently is free from any appreciable quantity of volatile material. The black residue in the distilling flask is extracted several times with ether. Upon evaporation of the ether, crystallization takes place, usually within a few days. The ether extract from most samples of sawdust crystallized within twenty-four hours, while other extracts from a different source of wood failed to crystallize satisfactorily when given several weeks. The best yield of crystals is obtained from sound wood that has been recently felled. Acetic acid is invariably a component of the ether extract.

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[1] Maintained at Madison, Wis., in cooperation with the University of Wisconsin.

[2] This is part of a paper presented at the seventy-ninth annual meeting of the American Chemical Society at Atlanta, Ga., April 7–11, 1930. Reprinted by permission from the Journal of the American Chemical Society, 55, 1728 (1933).

[3] Perkin and Everest, "The Natural Organic Colouring Matters." Longmans, Green & Co., London, 1918.

After crystallization of the concentrated ether extract has occurred, the crystals are purified by dissolving them in hot alcohol and precipitating once or twice with benzene and finally with water. The crystals thus obtained are thin, glistening flakes, odorless and tasteless. They are slightly soluble in cold water, more freely in hot water, slightly soluble in ether, soluble in glacial acetic acid and very soluble in alcohol. They dissolve readily in dilute alkalies, giving a bright red which gradually changes at the surface to a brown, forming at the same time a brown amorphous precipitate. This brown material exists in considerable quantity in redwood liquors. In cold concentrated sulfuric acid, the crystals dissolve with a deep red color. They burn with a luminous flame, giving an odor of a phenol and leave no ash.

Anal. Found: C, 68.7, 68.4, 68.4; H, 6.13, 6.07, 6.17; nitrogen, sulfur and halogen are absent.

Molecular weight determinations with absolute alcohol by the ebullioscopic method, with glacial acetic acid by the cryoscopic method, and with camphor by the method of Rast,[4] did not give consistent values.

With lead acetate and with stannous chloride, sequoyin gives a white colloidal precipitate that is not stable in the presence of alkali; with ferric chloride a permanent green is produced. It reduces Tollens' ammoniacal silver nitrate reagent very readily but gives no precipitate of cuprous oxide with Fehling's solution. Methoxyl (OCH_3), carboxyl ($COOH$) and carbonyl (CO) groups apparently are absent. Acetylation with acetic anhydride at 100° yields white microscopic crystals melting at 104 to 106°.

The percentage acetyl (CH_3CO) of these crystals, as determined by the method of Perkin,[5] equals *35.8 to 35.3%*.

The properties just described fail to correspond with those of any substance previously described in the literature. The empirical formula suggested for sequoyin is $C_{36}H_{38}O_{10}$. More information in favor of this formula will appear later in this report. Calcd. for $C_{36}H_{38}O_{10}$: C, 68.6; H, 6.08; CH_3CO for octaacetate, 35.7.

By dry distillation or fusion with potassium hydroxide, a dark brown oil having a decided phenolic odor is obtained. It has not been characterized, as the amount obtained was very small, and appears to be a mixture of two or more phenolic substances. Fusion with glycerin at 200 to 210° for three-quarters of an hour gives two compounds melting at 185 and 216°, respectively.

Preparation of Sequein and Sequeinol.—Upon heating sequoyin with 5 per cent sulfuric acid for several hours, two crystalline compounds may be obtained. They appear together or separately upon cooling the solution. They are separated from one another by fractional crystallization; sequein, which is the more soluble in alcohol, crystallizes in long slender white needles that melt sharply at 190° (uncorr.) when pure. The other, sequeinol, crystallizes from hot dilute alcohol in short needles that melt with some decomposition at 242° (uncorr.).

Sequein has properties similar to the parent substance. It has been obtained in yields up to 50.0 per cent. It crystallizes from slightly acid solutions with water of crystallization, which it loses at 100 to 105°. The crystals are white, but after drying in a desiccator they become brown externally. When white they are tasteless, but after becoming brown they are bitter. Heated at temperatures above its melting point it decomposes and leaves a bulky carbonaceous residue. It is only slightly soluble in cold water, more so in hot water and is dissolved with facility by alcohol. Sodium bicarbonate solution dissolves it incompletely. Sequein could be used as an indicator, its tincture being very sensitive to free alkalies and alkaline salts, with which it gives a bright red, while with acids it is yellow. It exhibits phenolic properties, adds bromine, and an alcoholic solution produces a transient green with ferric chloride. Basic lead acetate yields a violet precipitate, which gradually darkens on exposure to the air. Neutral lead acetate produces a slight reddish precipitate, the filtrate of which is a bright red. Stannous chloride gives a permanent rose-colored precipitate. An ammoniacal solution becomes a bright cherry red, ultimately changing to a brown. Upon the addition of acetic acid to this brown solution a brown precipitate is deposited. This precipitate fuses at temperatures over 250° and burns completely without the formation of ash. It gives a deeper shade of red with alkalies than the original compound. With potassium permanganate, sequein is oxidized to a brown humus-like substance that is devoid of any color-producing properties, while with nitric acid, oxalic acid (m. p. 99°) has been obtained. Sequein gives no precipitate with Fehling's solution, nor is it affected by phenylhydrazine. With hydrogen chloride in a dry ethereal solution, it forms a red oil from which the crystals (m. p. 190°) are again obtained upon bringing in contact with water. Wool mordanted with potassium bichromate is dyed a reddish-brown.

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[4] Rast, *Ber.*, 55B, 1051–1054 (1922).

[5] Perkin, *J. Chem. Soc.*, 87, 107 (1905).

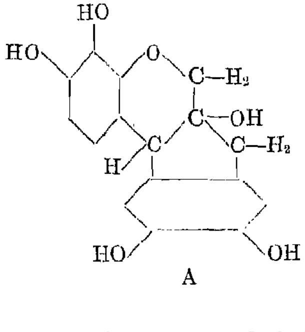
Anal. Found: C, 67.40, 67.36; H, 5.63, 5.59.

Molecular weight determinations by the method of Rast using camphor as a solvent gave 356 and 358; by the ebullioscopic method using absolute alcohol as a solvent the values 345 and 336 were obtained.

The above analyses, therefore, correspond to a compound of the empirical formula $C_{20}H_{20}O_6$.

Calculated for $C_{20}H_{20}O_6$: C, 67.38; H, 5.66; molecular weight, 356.16.

Preparation of Sequein Hexaacetate.—Sequein is acetylated by boiling with acetic anhydride with or without the aid of a catalyst, such as sulfuric acid, and also with acetic anhydride and pyridine at room temperatures. Upon adding water to the cooled reaction mixture, the acetylated derivative separates out. After recrystallizing from hot alcohol it may melt at 124 or at 114°. The lower-melting derivative is the one most commonly obtained. The difference in melting points is undoubtedly due to the formation of two isomers.



A

Analyses on the acetylated derivative, m. p. 114°; Found: C, 62.62; 62.71; H, 5.43, 5.41; acetyl (CH_3CO), 42.1, 42.2.

Molecular weight, average of several determinations, gave 607. These values calculated for a hexaacetate compound. Calcd. for $C_{20}H_{14}O_6 \cdot 6(CH_3CO)$: C, 63.13; H, 5.32; CH_3CO, 42.4; molecular weight, 608.25.

Attempts to characterize the products of degradation of sequein were not successful in that only a small amount of the pure compound was available. Fusion with potassium hydroxide, or dry distillation with diminished pressure, yields a brown oil having a very pronounced phenolic odor. During dry distillation orange-colored crystals may be seen momentarily in the receiving flask before dissolving in the distillate.

The residue from the hydrolysis of the acetylated product droxide, or dry distillation with diminished pressure, yields a brown oil having a very pronounced phenolic odor. During dry distillation orange-colored crystals may be seen momentarily in the receiving flask before dissolving in the solvent is evaporated. This material dissolves readily in dilute sodium hydroxide with a purple color and is precipitated as a brown oil upon the addition of an acid. All attempts to induce it to crystallize have failed. Upon exposure to the air it gradually darkens to a black granular mass.

Of the naturally occurring coloring principles the properties of sequein approach those of the dihydropyran group, of which hematoxylin and brasilin are the most important representatives. Brasilin is obtained from *Caesalpinia braziliensis,* while hematoxylin is derived from *Hematoxylon campeachianum.* The constitutional formula of hematoxylin accepted by W. H. Perkin and his co-workers after a series of extensive researches is shown as (A). On oxidation, hematoxylin gives rise to the actual dyestuff hematein, which dissolves in alkalies with a deep red color that is destroyed by excessive oxidation. Sequein has a larger molecule than hematoxylin, by reason of one or more side chains.

On the Properties of Sequeinol.—Sequeinol is soluble in alcohol and is insoluble in cold water, sodium carbonate solutions or carbon tetrachloride. With dilute alkalies it dissolves readily without color and is precipitated from alkaline solutions as microscopic needles with carbon dioxide or with dilute acids. It contains, therefore, no carboxyl group, but has phenolic properties. A clear emerald color is obtained with ferric chloride in 95 per cent alcohol. Fused with finely ground potassium hydroxide at 220° for twenty minutes, it retains its original melting point, 242°.

Anal. Found: C, 69.97, 69.97; H, 6.55, 6.53.

Molecular weight by the ebullioscopic method using absolute alcohol as a solvent gave 280 and 288.

These values correspond for a compound with the empirical formula $C_{16}H_{18}O_4$: Calcd. for $C_{16}H_{18}O_4$: C, 70.03; H, 6.61; molecular weight, 274.14.

Preparation of Sequeinol Tetraacetate.—Heating with acetic anhydride in a water-bath with or without sodium acetate gave a product which crystallized from hot alcohol in short needles melting at 176 to 177° (uncorr.). The percentage acetyl of these crystals when determined by the method of Perkin was 38.51. Molecular weight determinations gave 446 and 466. Calcd. for $C_{16}H_{14}O_4 \cdot 4(CH_3CO)$: CH_3CO, 38.68; molecular weight, 442.2.

Results indicate that there are four hydroxyl groups in sequeinol. No compound with like properties has been found in the literature.

On dry distillation under reduced pressure an amber-colored oil is obtained as a distillate. It is insoluble in water, benzene and carbon tetrachloride, but is dissolved with facility by alcohol or ether. An aqueous suspension with ferric chloride gives a transient yellow-green color. With the addition of dilute sodium bicarbonate to this ferric chloride solution a red color is formed which indicates the presence of catechol.[6]

From the residue remaining from the acetyl determinations of sequeinol, small hard brown crystals are obtained. They melt at 218°, burn with a luminous flame, and leave no ash. They are insoluble in water, soluble in hot alcohol, give no color with ferric chloride and are precipitated instantly from alkaline solutions with acids.

On the Constitution of Sequoyin.—The acid filtrate from the hydrolysis of sequoyin reveals nothing of importance. It contains no reducing material, which demonstrates the absence of sugars in sequoyin.

Sequeinol apparently is not a decomposition product of sequein. Further treatment of sequein with sulfuric acid under the conditions for the breaking up of sequoyin gave no additional sequeinol. A formula of the pyran type for sequein provides for a half acetal linkage with sequeinol in sequoyin. A labile half acetal linkage is the most logical to explain the splitting of the sequoyin molecule with a dilute mineral acid to form two compounds, both of which have no free carboxyl group.

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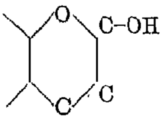
[6] Allen, "Commercial Organic Analysis," 5th ed., Blakiston, Philadelphia, 1925, p. 338.

Sequein is, therefore, concluded to have a hydroxyl group on the carbon atom adjoining the oxygen in the pyran ring. Upon acetylating such a compound, the ring structure is very likely to be broken. This explains the formation of sequein hexaacetate, and also why sequein is not recovered again after the hydrolysis of sequein hexaacetate.



Sequoyin having the half acetal structure just mentioned should, therefore, have two of its ten oxygen atoms unaffected by acetylation. This is confirmed by experimental evidence in that the octaacetate derivative is obtained upon acetylation.

The summation of sequein and sequeinol less one H_2O taken up on hydrolysis is equivalent to the formula $C_{36}H_{36}O_9$. Our analysis of sequoyin demonstrates that it possesses the formula $C_{36}H_{38}O_{10}$. One molecule of water must, therefore, be lost during the process of hydrolysis.

On the Properties of Isosequein.—This compound was obtained from only two redwood specimens in the green condition. The amount available for experimental investigation was small. After repeated crystallizations from hot alcohol it was finally obtained in clusters of red needles, which melt sharply at 188°. A dilute solution gives a violet color gradually darkening with alkalies, which is of similar intensity and sensitivity to that produced when proportionately dilute unpurified redwood extracts are treated with alkali. In acid solutions it is yellow. It possesses phenolic properties, producing a dark green with ferric chloride.

Molecular weight determinations by the method of Rast gave 348 and 353. Structurally it is believed to be related to sequein.

SUMMARY

Two crystalline red color-producing compounds, sequoyin and isosequein, have been isolated from the heartwood of redwood. These two compounds, together with their decomposition products, are believed to be largely responsible for the color changes in redwood. Through hydrolysis with dilute acids sequein and sequeinol have been obtained from sequoyin. The compounds do not appear to have been described in the literature previously.

CHAPTER 43

SEASONAL CHANGES IN WOOD IN RELATION TO SUSCEPTIBILITY TO ATTACK BY FUNGI AND TERMITES

BY

CHARLES A. KOFOID

The variation in the incidence or the extent of attack by the same species or even by the same colony of termites upon different pieces of lumber of the same species of wood in comparable locations in the same building are striking features often detected in the examination of infested structures. The abundant innervation of the cutting jaws and the abundance and variety of sensory nerve endings in the mouth parts of termites equip them to detect the odor, taste, and resistance of the wood eaten. It is a reasonable assumption from the structure and observed behavior of these insects that directed choice, rather than random chance, determines, in an unknown but probably considerable degree, this seemingly lawless and aberrant pattern of their selection of structural elements attacked.

The assumption that the directive factors for these choices lie to a considerable degree in the species of wood itself is proved both by our field observations and by controlled laboratory experiments (chap. 41). The choice of particular structural elements within one and the same species of wood within the building is also observable on inspection and in controlled laboratory experiment. Termites imprisoned in experimental blocks will leave one species and enter another, or abandon several blocks to enter one other of the same species.

The factors within the wood itself which function in determining these choices appear to be related to the process of feeding. The amounts of wood eaten in blocks with different physical and chemical characteristics, from different trees, differ considerably under controlled laboratory conditions (chap. 41).

The growing tree is not a static mechanism, the same at all seasons of the year, but a dynamic one, changing with the seasonal rhythm of metabolism and growth. In the course of this rhythm very considerable changes take place in the rates of production and amounts of organic substances produced, in the quantities and rates of movement of sap, in the amounts and locations of the sugar, starch, and compounds of nitrogen in storage, and in the colloidal state of the cell wall as influenced by the ripening and seasoning of the wood, in the course of which both cellulose and lignin thicken and harden.

These seasonal changes profoundly affect the supply of the food materials required both by fungi and termites, which in turn are correlated with the location and extent of termite damage. While it is customary to refer to termites as eating wood, this reference is incomplete, for termites cannot live on cellulose alone, but must have nitrogenous substances, or proteins, and vitamins (Cook, 1933), obtainable from the contents of the wood, or from the fungi in the wood, which in turn are dependent on the carbohydrates and mineral salts of the wood.

During the spring and early summer the sap is in rapid movement; mineral salts enter the tree in larger amounts; phosphates and nitrates are utilized in forming the increasing amounts of proteins in growing leaves and shoots; stored starches, sugars, and reserve cellulose (debatable) are depleted; and new and delicate cell walls are formed. In the winter season, on the other hand, all activities are at a minimum, little or no storage is in progress, and the season's wood has completed its development.

The extent of change in the quantities of these substances which are of physiological importance to fungi and termites is considerable. The total nitrogen of the wood varies about 50 per cent, and the reserve starch and sugar may fall as low as 10 per cent of the maximum. Reserve cellulose is known in some seeds, but its occurrence and withdrawal in wood of tree trunks is not proved, though it has been suggested.

Much more investigation is needed for a comprehensive picture of the seasonal rhythm of chemical and physical changes in both sap- and heartwood of the tree trunks. MacDougal and Smith (1927) have recently reported that living cells have been found in the heartwood of redwood, *Sequoia sempervirens,* as follows:

> Certain features of behavior of the trunks of the California Redwood uncovered by our study of the hydrostatics of this tree led us to examine the parenchymatous cells of the trunks. There are two different types of living cells in newly-formed secondary xylem of *Sequoia sempervirens:* wood-parenchyma cells that stand in vertical files scattered among the tracheids, and ray-parenchyma cells. As in most other woody stems, the wood parenchyma and ray-parenchyma cells of the alburnum or whitish sapwood are living and densely packed with starch.
>
> The change from alburnum to duramen (heartwood), macroscopically recognizable in *Sequoia* by a brownish-red coloration of the duramen, is accompanied by a disappearance of starch and protoplasts from all wood-parenchyma cells and the formation of an orange-colored resin that completely or partially fills the lumen of the wood-parenchyma cells. For this reason wood-parenchyma cells are often called resin cells. The transition from alburnum to duramen is also accompanied by a disappearance of starch from the ray-parenchyma cells but this disappearance of the starch is not always followed by death and disintegration of the protoplasts. These living ray cells of the duramen have a thin layer of cytoplasm next the wall, a conspicuous nucleus, and a large central vacuole. The ray cells may remain unchanged for a long time and we have observed ray-parenchyma 70 layers deep in the heartwood with clearly defined protoplasts and apparently normal nuclei. As the sapwood in such trees included 21–23 layers these cells were about a century old. Cells of older annual increments in these stems also appeared to be living but this could not be determined with certainty since the granular nature of the cell contents obscured the nuclei. Some trees have ray-parenchyma cells that show a granular cytoplasm and small droplets of resin shortly

> after the transition from duramen to alburnum; still others have the same behavior in ray-parenchyma and wood-parenchyma and both elements in the outermost ring of heartwood contain resin only.
>
> The reasons for this marked variation in the behaviour of ray-parenchyma cells are as yet unknown. The age of the tree does not appear to be a factor, for we have found both conditions in young and in old trees. Neither is there any sharp correlation with the environment. Trees high on the dry flanks of hills or deep in the canyons of this vicinity may have living ray cells deep in the duramen.
>
> That these cells should survive during the pronounced changes in chemical constitution of the wood, altered composition of the sap and lessened oxygen supply is a remarkable occurrence. The nuclei undergo but little change and a superficial examination suggests consumption of the carbohydrates. The well-known abrupt diminution of starch in the rays occurs in the redwood at the stage of transition from sap to heartwood. The ratio of length of life of these cells to that of their growing period is the highest known. Full size is reached almost at once—within a few days—life may continue for a century or four thousand times the duration of the growing period. . . .
>
> In what way the existence of these numerous strips of living cells in the heartwood, which may reach an age of more than a century, affect the pressures and movements of liquids and gases in this tree is yet to be determined.

MacDougal also informs us in correspondence that "the fact that no fermentation ensues in the first water-extracted solutions from redwood trees, but that after a few extractions fermentation does ensue suggests the presence of inhibiting agents. 'Weathering' of wood would affect such substances. There are of course great individual differences among trees, although I have not tested differences in inhibiting or protective substances. Then too, the amounts of starch left behind in old layers varies widely, as may be easily demonstrated. There is comparatively little radial movement of material in the redwood."

The removal of volatile and water-soluble extractives by weathering may be the reason why sawn redwood poles at Fort Bragg, California, were found after 40 years of service to be attacked by the dry-wood termite. The roof timbers of redwood of the San Miguel Mission, after 136 years of service, were found in 1931 to be attacked by this same termite. Finishing lumber of redwood in the old Customs House at Monterey, California, built in 1814, was likewise found in 1929 to have been attacked by this termite. The natural reservoirs of this termite in the forests in these regions are considerable in extent today and presumably were adequate in the past to have afforded repeated opportunities for infestation by the swarming alates. It was only after long years of service in these structures and the slow evaporation of the volatile extractives that these structural elements succumbed to the termites.

In the forest, on the other hand, down logs of redwood in the very centers of distribution of *Zootermopsis* remain within their bark or the decaying mantle of sapwood, untouched by termites for centuries, presumably because the continuously maintained moisture in the trunk retains the original toxic extractives, conserved from evaporation and but little modified by leaching.

The high toxicity to termites of Port Orford cedar is due to the volatile extractive which that wood contains. This toxicity decreases with evaporation of the toxic substance and may rapidly disappear.

These findings are suggestive that these substances of the heartwood, at least of redwood, have some part in the mechanism of seasonal changes.

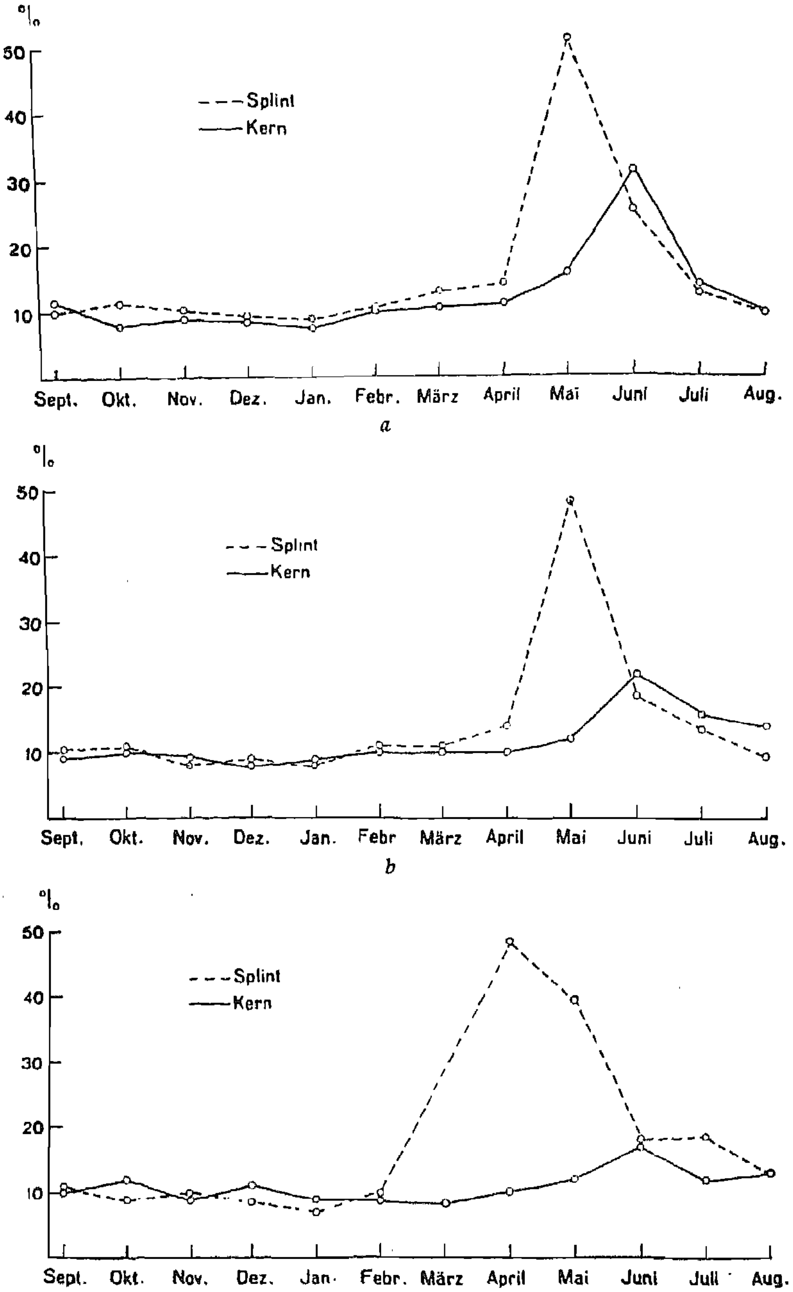
A very complete investigation of some phases of these seasonal changes in the European Norway spruce *(Picea excelsa)* and silver fir *(Abies alba)* have recently been made in the Forestry Department of the Technical High School at Zürich, Switzerland. Professor H. Knuchel (1930) has studied the influence of the time of felling trees and of subsequent seasoning upon the physical characteristics and use-qualities of the logs and lumber. Professor E. Gäumann (1930) has also investigated the influence of the season of felling upon the durability of the logs and the lumber, with special reference to their reaction to fungus attack in the ground, in storage, and under controlled laboratory conditions. The two papers are mutually supplementary. Certain data from Dr. Gäumann's paper are of especial interest with reference to the problem of varying resistance of different samples of the same species of wood to termite attack, since they deal with the extent of damage by four well known wood-destroying fungi upon logs and lumber from trees felled at monthly intervals throughout the entire year.

A summary of Gäumann's (1930) findings follows, and his figures 7–9, and 14–15, are reproduced in our figures 134 and 135.

There is an effect of the time of felling upon the durability of the Norway spruce and the silver fir, but the effect differs with the technical handling of the wood. Investigation shows that in the case of logs left in the bark for a year those felled in September–October have a lower incidence of fungus damage than those felled in March–June. This advantage is, however, practically disposed of by the circumstance that these autumn-felled logs are heavily attacked in the following spring by beetles. In logs with the bark removed and held for a year the attack by fungus is in every instance less than in controls with the bark retained, both in logs on the ground and in dry storage. Under these conditions also the attack by fungus is least in the logs felled in September–October and greatest in those felled in March–June.

In sawn timbers set in the ground in meadow land for two years the resistivity depended upon the degree of seasoning of the wood. In unseasoned timbers the fungus attack in summer-felled (May–July, inclusive) wood was from three- to five-fold greater in the sapwood, and twice as great in the heartwood as it was in fall- and winter-felled (September–January) wood. In case, however, that the timbers prior to exposure to fungus had been seasoned in storage or weathered for one year, the fungus attack in summer-felled sapwood was only twice that of the winter-felled, while in the heartwood it was even less and showed greater irregularities.

Laboratory investigations on wood derived from similar monthly fellings of Norway spruce and silver fir under constant temperature and optimum conditions of moisture, and infected with pure cultures, respectively, of four species of wood-destroying fungi, indicate that the resistivity to fungus attack in the practical field tests has two components. These are the climatic factors affecting the growth of fungi and the factors inherent in the wood itself. These internal factors include the growth process while the annual ring



a

b

c

Fig. 134. *a*. The seasonal changes in the total extractives of Norway spruce freshly felled each month of the year, after being set as timbers in the ground on meadow land for two years. The sum of the ether, alcohol, water, and soda extracts averaged for 30 samples

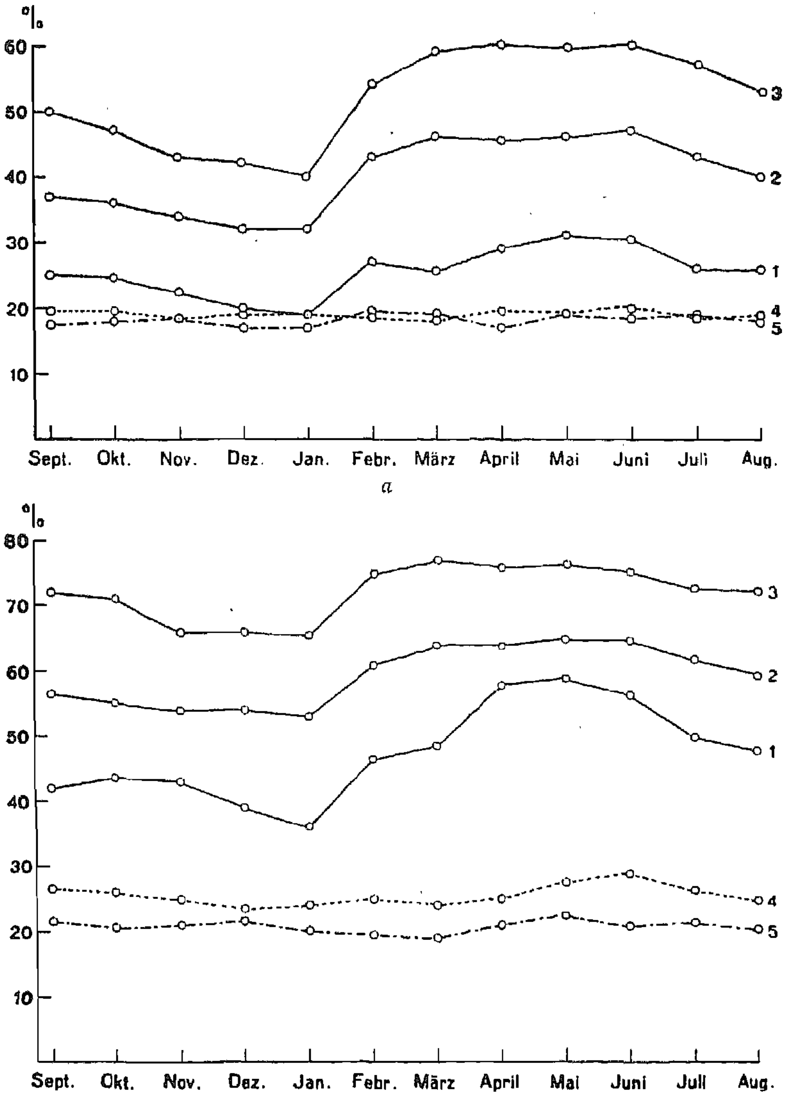


Fig. 135. *a.* Loss of weight in per cent of original weight due to fungus attack by *Lenzites abietina* on sapwood of silver fir felled each month from 10 trees at each felling. 1. After 3 months. 2. After 6 months. 3. After 9 months. 4. After 1 year of seasoning in stock under cover. 5. After 1 year of weathering. After Gäumann (1930, fig. 14). *b.* The same for heartwood of silver fir. After Gäumann (1930, fig. 15).

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at each felling is plotted in per cent of the total wood. "Splint"=sapwood: "Kern"=heartwood. After Gäumann (1930, fig. 7). *b.* The same for silver fir. After Gäumann (1930, fig. 8). *c.* The same for silver fir after one full year of weathering and the same exposure. After Gäumann (1930, fig. 9).

is forming, and the closely related maximum of metabolic change in the trunk of the tree. Both of these are influenced in their seasonal and quantitative relations by climatic and local conditions. The data unquestionably indicate throughout that these internal factors of the wood itself are correlated with lowered resistance to attack by fungi in the summer-felled logs as compared with winter-felled ones.

The cause of the differential resistivity to fungus attack, in the opinion of Dr. Gäumann, lies less in the cell contents, such as the carbohydrates, nitrogen, phosphorus, potassium, and resin, than in the differential "colloidal-chemical" condition of the cell wall itself, especially of the cellulose and xylans, but less so of the lignin. The dry storage of the logs or timber for a full year reduces the susceptibility of the wood to attack by fungi about one-half. The effect of the felling season on susceptibility to fungus is still observable in the seasoned wood, but is so small as to have little practical significance. This loss of susceptibility is due to the ripening process of colloidal-chemical changes in the cellulose and xylans.

Weathering in the open for a full year seems to bring about irreversible changes in the consistency of the cellulose, which practically eliminate the differences in the resistivity of both sap- and heartwood resulting from the season of felling. After a year of weathering summer-felled wood is almost as resistant as winter-felled.

These conclusions from this extensive, carefully planned investigation of the relation of seasoning to resistivity to fungus were anticipated by centuries-old folk-lore rules which called for the thorough weathering for several years of timbers to be used in bridges, roofs of cathedrals, and other large and permanent wooden structures.

The bearing of this and other investigations showing the seasonal changes in the chemical and physical properties of the growing tree trunk of the lumber-producing conifers and heartwoods upon the prevention or control of termite attack is enhanced by our findings of the relations of termites to fungi in the wood eaten by them from the surface of the walls of their burrows (chap. 9).

Two important inferences may be drawn from the facts revealed by Gäumann's work. First, summer-felled wood has much less *initial resistance* to attack by fungi and presumably therefore by termites than has winter-felled wood. Second, thorough seasoning, especially weathering in the open, for one full year, progressively so changes the wood that this seasonal differential is largely eliminated. It should be noted that it is only the initial relatively greater susceptibility of summer-felled wood which is thus eliminated. A residual susceptibility to fungus and termite attack still remains, and that of sapwood still exceeds that of heartwood (fig. 135) even after seasoning.

If termites can and do exercise some choice of wood in their initial settlement, and also choose the wood into which extensions of the colony are pushed, and, furthermore, if the susceptibility of the wood to fungus attack influences their choice, the facts presented by Gäumann are significant in the following respects:

(1) Sapwood will be more attractive to termites than heartwood, whether green or seasoned.

(2) Initially, before seasoning, summer-felled wood will grow fungi and invite termite attack more than winter-felled. Possibly the softer, less dense, and less hardened and lignified cell walls make the spring wood physically more attractive than the ripened wood. Possibly the cell contents are also influential.

(3) Seasoning and weathering place summer-felled and winter-felled wood nearly on a par *as to the attack of fungi,* and in the particular feature of physical structure present little differential for choice.

(4) It is possible that seasonal differences in the amounts of organic nitrogen and phosphates included in the total extractives may affect the choices of termites independently of fungi. It is customary to use inorganic salts of these substances in the culture of fungi. Termites, on the other hand, require organic compounds. The amounts of these substances in wood, especially in heartwood, are small. Possibly fungi assist the termite to accumulate the necessary amount. Cannibalism is frequent among termites, and also assists in providing nitrogen for the survivors. If casein is provided in experimental colonies cannibalism declines (Cook, 1933).

Much more integrated investigation on the total physiological processes in the tree trunk of the conifers is needed before an adequate understanding of the interrelations of wood, fungi, and termites can be acquired.

One other aspect of the problem should be emphasized. If wood which has not been thoroughly seasoned or weathered for a full year is used in a structure, especially sapwood, it tends to invite termite settlement or extension of the colony into that location. Unseasoned wood thus *places a premium on the initiation of termite attack.* A wider recognition, by both the producer and user, of the basic values of seasoning of wood is indicated.

CHAPTER 44

WOOD PREFERENCE TESTS

BY

O. L. WILLIAMS

It is a well known fact that when heartwood pieces of two or more species of trees are available to termites, one is usually damaged much more than the others, but quantitative data on the preferences shown within a given series of woods are lacking. It is desirable that some simple method for obtaining these data be made available. The experiments herein described were made for the purpose of testing such a method of determining the preferences shown by *Kalotermes minor* for the heartwood of five species of trees.

The five woods used were Douglas fir, cypress, redwood. Port Orford cedar, and western red cedar. Four test blocks ½ inch × 2 inches × 5 inches were cut from each of these species, and a hole ⅜ inch in diameter was drilled in the flat surface of each block to a depth of 5/16 inch. The blocks were then arranged in pairs, the holes coinciding to form cylindrical chambers into which ten nymphs of *Kalotermes minor* were introduced. The paired blocks were held together with rubber bands. The tests were made in moist chambers containing open dishes of water to maintain a saturated atmosphere.

Each kind of wood was paired off with each of the others, making ten tests in all, as follows:

1. Douglas fir..........redwood
2. Douglas fir..........Port Orford cedar
3. Douglas fir..........cypress
4. Douglas fir..........western red cedar
5. Redwood..........Port Orford cedar
6. Redwood..........cypress
7. Redwood..........western red cedar
8. Port Orford cedar..........cypress
9. Port Orford cedar..........western red cedar
10. Cypress..........western red cedar

The tests were allowed to continue for a period of two months, during which time ten sets of observations were made, recording (1) the number of termites in each piece of wood of each test, and (2) the number of termites still alive. At the end of two months the blocks were opened, the number of termites in each kind of wood noted, and the number of millimeters of runways in each kind of wood measured. Table 49 summarizes the results.

Although the above table demonstrates the manner in which the woods may be arranged in a "preference" series, going from Port Orford cedar, least preferred, to western red cedar, most preferred, it must not be concluded that this arrangement is significant for these woods. The histories of the wood samples employed in these tests are unknown, and the number of tests made is far too small to yield sufficiently conclusive data for the arrangement of a preference series. It is obvious that the seriation, the length of runways, and the survival of the termites will be affected not only by the species of wood tested but also by the specific gravity, rate of growth, hardness, contents affecting taste and food value, and the age of the wood within a species. A larger number of tests in which these factors are coordinated may be expected to reveal a preference relation that will have significance. However, the tests made do fulfill their purpose in that they demonstrate well the application of this method for determining wood preferences shown by dry-wood termites.

TABLE 49

	Average number of termites present on ten different days	Millimeters of runways excavated	Number of termites alive in each kind of wood at close of test
Port Orford cedar	0.24	18	1
Cypress	4.45	20	6
Redwood	3.67	33	12
Douglas fir	6.40	90	23
Western red cedar	7.20	167	26

CHAPTER 45

TESTS ON WALLBOARDS AND INSULATING MATERIALS

BY

O. L. WILLIAMS

INTRODUCTION

Within recent years a great many structural products in the nature of wallboards, insulating, and acoustic boards have been manufactured and placed upon the market. The majority of these products contain cellulose, and in view of the fact that termites are known to live upon cellulose, it becomes important to know to what extent such products are likely to be damaged when subjected to termite attack. The Termite Investigations Committee undertook the testing of a considerable number of these commercial products. The results of the various tests are given in this report.

All of the tests herein reported were conducted in the laboratory, and in every instance the termites were brought into immediate contact with the material in question, thus effecting an accelerated test. New materials were used in all tests, so that the resistivity as reported is in every case the initial resistivity, and cannot be taken as an indication of what the resistivity might be after a period of exposure to conditions of use. No attempt was made to determine the resistivity quantitatively, as was done with the various species of wood, because of the many kinds of materials tested. If the material under consideration was badly damaged by the termites it was considered nonresistant; if the material was only very slightly damaged and all the termites were killed, it was considered resistant to termites; if the material was undamaged and the termites were killed, it was considered termite-proof.

In general, the method employed in making the tests consisted of placing fifteen termites of the species *Kalotermes minor* in contact with the material to be tested, and observing the results to both the material and the termites. Modifications of method were used with products of different kinds as follows:

Untreated materials of homogeneous structure: The test pieces were cut into 6 cm. squares, placed in 9 cm. Petri dishes, and the termites applied. Water was added from time to time as required.

Untreated materials made up of layers of different composition: The test pieces were cut into 6 cm. squares. The layers of different composition were then separated from one another and each tested separately as above.

Treated materials: All of the treated materials tested were homogeneous in structure; they were cut into 6 cm. squares, moistened, the termites applied to the surface to be tested and confined to that surface by covering with a 4 cm. Petri dish sealed in place with paraffin. In all treated materials, both upper and lower surfaces were tested.

The results obtained by these modifications of the general method are strictly comparable, as in all cases the termites were brought into direct contact with the material to be tested. Each test was allowed to continue until the board was obviously badly damaged, or until all the termites were killed.

TEST RESULTS

1. UNTREATED PRODUCTS:

The results of the tests on untreated products are given below according to the structure of the materials.

Fiber boards homogeneous in structure, made of wood, bark, cane, etc. These are of two kinds: first, those of rather open structure, light, soft, and adapted to insulation purposes; and, second, those of the same materials compressed into a hard board adapted to flooring, paneling, etc. All products of this group were found to be non-resistant to termites, the softer boards being destroyed more rapidly than the harder boards.

Fiber boards made of a soft, wool-like mat held between heavy paper facings. Such products were found to be non-resistant to termite attack, both the paper facings and the insulating mat being readily destroyed.

Wood and paper combination boards. These consist of thin, narrow strips of wood held between heavy paper facings. Tests on these boards demonstrated the inability of either the paper facings or the wood to withstand termite attack.

Cork boards. All cork boards tested were rapidly destroyed by termites.

Eel grass insulation. This product consists of a mat of eel grass held between paper facings. The paper facings proved non-resistant, but the eel grass mat was found to be toxic to the termites.

Excelsior boards. Two kinds of composition boards in which excelsior was incorporated were tested. The first made up largely of excelsior held together with a plaster binder proved to be termite-proof; probably some toxic agent in the plaster destroyed the termites. The second, made up largely of a fine cement, but containing a small amount of excelsior, proved to be resistant to termites. This resistant quality was due to the fact that the wood particles were so completely surrounded with cement as to be inaccessible to the termites, and not to any toxic agent in the cement.

Plaster boards. These consist of a layer of plaster held between two layers of heavy paper. The paper covers were non-resistant to termites, the plaster layer termite-proof.

In addition to these commercial boards and insulations containing cellulose, a few miscellaneous structural products containing no cellulose were tested to determine whether or not termites could construct runways through them. It was found that termites can construct passageways through mineral wools of various kinds, glass wool, and gypsum without damage to themselves. However, such materials would probably never be extensively damaged, because termites are unable to derive nourishment from such cellulose-free substances.

2. TREATED PRODUCTS:

The Termite Investigations Committee tested three commercial "termite-proofed" boards. All three of these boards were treated especially to resist termite attack, and all were successful in so doing. The Committee was not informed as to the methods or the toxic agents used in preparing these products.

CONCLUSIONS

From the tests made on various structural products it can be safely concluded that nearly all of these products which contain cellulose are non-resistant to termites. Special treatment is necessary to make products of this kind resistant or termite-proof. That such materials can be made termite-proof is demonstrated by the tests of three commercial boards treated specifically to prevent termite damage. These treated boards were undamaged after subjection to termites.

PART IV

PREVENTION AND REPAIR OF TERMITE DAMAGE

Chapter 46

GENERAL RECOMMENDATIONS FOR THE CONTROL OF TERMITE DAMAGE

BY

THE EXECUTIVE COMMITTEE

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Principles

As a result of investigations made by the Committee, it is evident that one or more of the following underlying principles must be applied in order to prevent termite damage to structures made wholly or partly of wood:

1. Make the structure or material which is to be protected inaccessible to termites (chap. 48).
2. Use wood which is unavailable as food or undesirable to termites as a source of food supply (chaps. 35–37, 41–43).
3. Discourage colonization or breeding of termites in the vicinity of the structure or material which is to be protected (chaps. 14, 20, 21, 24, 47, 48).

Elsewhere in this report it has been stated that termites use as food the cellulose which makes up a large part of the woody tissue of trees, shrubs, and other plant life. The form in which such cellulose is most readily available to termites is in those products of tree-growth which are somewhat loosely classed as wood. It should be understood that cellulose also occurs in a form available to termites in such articles as clothing, rugs, papers, book covers, and many other manufactured products. The word wood in this chapter implies any cellulose-containing material.

General Recommendations

The application of the above mentioned three principles to the problem of control of termite damage is embodied in the following general recommendations, no one of which will completely answer every case. An intelligent choice of one or several of these recommendations must be made in order to meet the conditions presented in any specific case.

The Committee makes the following general recommendations:

A. Recommendations 1 to 3 represent the best approved practices for the *prevention* of damage by termites.

1. The methods of construction employed for new structures and for the repair of existing structures should be such as to keep all wood not adequately treated away from contact with the ground (chap. 48).

2. If the most complete protection from damage by termites is required, and if feasible, all wood which is placed in the ground or in contact with the ground should be impregnated according to standard specifications (p. 550) with chemical preservatives known to give protection (chaps. 34–36, 41).
3. Wherever termite damage to wood not in contact with the ground is to be prevented, and when this cannot be done by methods of construction (chap. 48), and if feasible, wood should be used which has been impregnated according to standard specifications with chemical preservatives known to give protection (chaps. 34–36, 41). This applies to attack by dry-wood termites, as well as to attacks by subterranean termites through covered runways over foundations.

B. Recommendations 4 and 5 are intended to apply where the use-life is relatively short, or where the most complete protection is not feasible.

4. Where pressure impregnation with chemicals known to give adequate protection is not feasible, and where a measure of protection greater than that afforded by untreated woods of most species is desired, the sound, seasoned heartwood of species known to be relatively unpalatable to termites (chaps. 41–43 and p. 548) should be used. The protection secured increases with the amount of toxic extractive present in the wood, and the duration of this protection depends upon the retention of this toxic amount of the extractive in the wood. The loss of extractive will depend in part upon the degree of exposure to the elements and to soil moisture.
5. Some protection may be had from wood treated by dipping, brushing, or spraying with chemicals toxic or repellent to termites, although, as will be seen on page 550, such methods are not included in the standard specifications. The degree and duration of protection attained depend upon the initial toxicity of the substance, its permanence in the wood, its concentration in the wood, and the integrity and thickness of the protecting coat.

C. Recommendations 6 and 7 are designed to reduce the probability that the structure will be subjected to termite attack.

6. Prevent and eliminate sources of termite infestation:
   (a) Remove all roots, stumps, and waste wood from the building site.
   (b) Remove all wood used in forms around concrete.
   (c) Destroy colonies of termites near and on the building site, and under and around the structure (subterranean termites, chap. 14; dry-wood termites, chap. 21).
7. In all cases provide a systematic plan of inspection and maintenance for all structures, whether or not protected in a recommended manner (chap. 47).

In the great majority of cases of termite damage in the United States which have come to the attention of the Committee, the damaged structures could originally have been made inaccessible to termites at very slight additional cost by employing well known methods of good construction. In the remainder of these cases termite damage would have been prevented by using wood unavailable or undesirable to termites as food, although the use of such materials might not always have been feasible. However, approved methods of construction, or the use of wood unavailable or undesirable to termites for food, cannot be considered permanently adequate unless supplemented by systematic inspection and maintenance of the structure. These important subjects are discussed in chapter 47.

The Committee recommends that wherever earthquake and tornado hazards prevail preventive measures against termite damage be established and continuously enforced. This can be accomplished by adequate provisions in building codes (chap. 54), by official inspection of buildings, by approved methods of construction and the use of suitable building materials (chap. 48), and through the architect and structural engineer in planning construction (chap. 56) and in supervision, and by adequate inspection on the part of the owner or occupant of the premises. For protection against damage by earthquakes the Committee also recommends that structures damaged by termites be adequately repaired by the restoration of all weakened structural members, and that sources of infestation be removed.

The earthquake in southern California on March 10, 1933, brought to light the fact, according to the report of the Coroner of Los Angeles County (see Los Angeles County Coroner's Jury, 1933, in bibliography), Homann (1933), and Wailes and Horner (1933), that wood frame buildings, whether finished with wood or stucco, suffered relatively minor damage, and that a considerable portion of this damage was due to the collapse of underpinning and structural members. Of the houses damaged by earthquake, many were found to be infested by termites. It is obviously difficult to assess quantitatively the relative contributions to earthquake damage by structural weaknesses, on the one hand, and by termite damage of such members, on the other hand. It is apparent, however, that termite damage adds to the earthquake hazard, especially in the case of that by the subterranean termite, whose main area of operations is in timbers near the ground.

The impartial and searching earthquake test establishes the fact that wood is eminently adapted for meeting the earthquake hazard in houses and other residential structures, and that the prevention of termite infestation is essential in maintaining the protection afforded by the use of wood.

The Committee recommends that arsenical preservatives be not used in the treatment of wood, wallboard, building paper, or other material used in dwellings or structures accessible to man, or in or on soil underneath such structures, as a treatment against termites. The arsenic compounds used as preservatives are all highly toxic to man and also present a toxic fume hazard in case of fire. Furthermore, termites and their burrows are universally infested by fungi, including many common molds (chaps. 1, 9). Fungi are also abundant in the soil in which termites live. A number of these fungi turn arsenical compounds into a volatile form, which diffuses through the air and slowly poisons persons breathing it. The entire number of species of fungi capable of making this transformation is as yet unknown.

Dr. C. D. Leake, Professor of Pharmacology in the University of California, an experienced toxicologist, has furnished the following statement concerning the danger arising from the use of arsenical compounds in building materials intended for use in human dwellings:

It is now well known as a result of the work of Sanger (1894 *a, b*) and Biginelli (1900), confirmed by Maasen (1902), that a gaseous arsenical substance, diethylarsine, is produced by the action of common molds growing in the presence of a great variety of arsenical compounds, both inorganic and organic. Gosio (1893, 1897) found *Penicillium brevicaule* more active than other molds in producing this volatile arsenical compound, but Schmidt (1899) found many other molds which act similarly. Thom and Raper (1932) verified and extended these findings.

These studies, substantiated as they are by many cases of chronic poisoning of an arsenical or arsine type in people who have lived in rooms the wall papers of which were impregnated with arsenical pigments, *indicate that the use of any arsenical compound*, proposed for keeping termites out of wood building materials or out of soil under houses, may cause the appearance of poisonous arsenical fumes in the dwelling as a result of the action of molds.

It is true, of course, that modern building methods insure better ventilation than used to be the case, and also that arsenical pigments are no longer employed in wall papers. It would, I think, be decidedly dangerous to public health to introduce into dwellings any building material which might be extensively employed containing any appreciable amount of any type of arsenical compound. There is a definitely established risk in such an undertaking, and should any untoward effects follow such an introduction, it would react unfavorably on the commercial concerns responsible for producing, distributing, and using the arsenic-containing product. Other relatively non-toxic chemicals are available for incorporation in building material for the purpose of protecting against termites. In view of these facts, it is my opinion that any agency responsible in any way for the public health would be unjustified in giving its approval to the producing and marketing of building materials impregnated with arsenicals. [See Anon., 1932; Gosio, 1892; Thom and Raper, 1932.]

The evidence before the Committee is insufficient to enable it to recommend specific chemicals for soil treatments. A discussion of the chemicals which have been investigated for this purpose will be found in chapters 34 and 40.

> For ground treatment under and around dwellings the following chemicals are only tentatively recommended, because of differences in soils, etc., namely: saturated aqueous solution of copper sulfate or of sodium fluosilicate; saturated aqueous solution of borax; or full-strength, crude liquid orthodichlorobenzene; or crystalline paradichlorobenzene.
>
> In case a building material containing arsenic or other poison is used in a building, such material should be required to have a permanent label on every square yard of the material, stating: "Poisoned with arsenic (or other substance)."
>
> In case the soil under or around a dwelling has been treated with arsenic or other poison, a permanent sign should be installed, reading: "Poisoned with arsenic (or other poison)."

METHODS OF PREVENTION

The methods suggested for carrying out these general recommendations are stated separately for subterranean and for dry-wood termites, and are grouped below according to the principles involved. Protection against subterranean termites will also afford protection against damp-wood termites.

It should be remembered that conditions which make attack by termites possible are usually also favorable to the more familiar processes of decay in wood products. Decay, a form of which is popularly spoken of as dry rot, is caused by plant growths called fungi. There are four factors essential to the life of both termites and fungi: food, air, moisture, and warmth. Food and moisture are the factors which can be most economically controlled in seeking to prevent damage by termites, and this fact provides the starting point for the majority of methods for termite control.

Methods of preventing attack by subterranean termites (chap. 14).

1. To make a structure or material relatively inaccessible to subterranean termites:
    a. Keep wood away from contact with the ground.
    b. Support untreated wood above the ground on a barrier of concrete, masonry laid in cement mortar, or/and wood which has been impregnated according to standard specifications with chemical preservatives known to be toxic to termites (p. 550).
    c. Prevent or fill cracks, and prevent voids in concrete or masonry walls, floors, and foundations. Use only mortar containing a proper amount of cement (chaps. 48, 56).
    d. Provide and maintain a metal shield as a barrier to runways below the wood to be protected. Bed wood plates, posts, and similar members on a newly laid mortar cap above the masonry or concrete foundation.
    e. Provide ample ventilation, especially in the substructure (chaps. 48, 56).
    f. Provide adequate drainage of soil beneath and around the structure (chaps. 48, 56).
2. To make a structure or material unavailable or undesirable as a source of food supply:
    a. Use wood impregnated according to standard specifications with suitable chemical preservatives known to be toxic to termites (p. 550).
    b. Where the most complete protection is not required or is not feasible, use the sound, seasoned heartwood of a species known to be relatively unpalatable to termites (p. 548), or wood treated with toxic chemicals by other methods than impregnation under pressure (chaps. 33–35).
3. To discourage colonization and breeding of termites:
    a. Provide adequate drainage of soil (chaps. 48, 56).
    b. Remove all possible sources of termite food supply, such as stumps, roots, and casual wood, in or on the ground under and around the structure (chap. 48).
    c. Provide ample ventilation, especially in the substructure (chaps. 48, 56).
    d. Find points from which swarming termites emerge and locate and destroy colonies from which the swarming has taken place (chaps. 14, 38).

Methods of preventing attack by dry-wood termites (chap. 21).

1. To make a material or structure relatively inaccessible to dry-wood termites:
    a. Keep materials or products under cover during the swarming season (chap. 53).
    b. Use paints or other deterrents as a covering for material to be protected. For temporary protection during the swarming season use a toxic chemical liquid spray or a poisonous dust (chaps. 37, 38, 53).

   c. Use screens over attic openings and close cracks and small openings in exterior walls (chaps. 48, 56).

2. To make a structure or material unavailable or undesirable as a source of food supply:
   a. Use wood impregnated according to standard specifications with chemical preservatives known to be toxic to termites (p. 550).
   b. Where the most complete protection is not required or not feasible, use the sound, seasoned heartwood of species known to be relatively unpalatable to termites, or wood treated with toxic chemicals by other methods than impregnation under pressure.

3. To discourage colonization and breeding of termites:

   Look for points from which swarming termites emerge, and locate and destroy colonies from which the swarming has taken place (chaps. 21, 38).

METHODS OF REPAIR

These methods are suggested as effective for both the prevention and the repair of termite damage. Every repair job should be treated as a prevention job as soon as the seriously damaged materials have been removed.

In addition to the methods for prevention listed above, the Committee suggests as essential the following methods for the repair of damage.

Subterranean Termites

1. Close all avenues between the ground and the material to be protected by interposing barriers of metal, concrete, or chemically treated wood (chaps. 48, 56).
2. Remove all structurally unsound material; destroy all removed material which contains live termites (chaps. 14, 48).
3. Poison the ground at points where runways leave it (chap. 40 and p. 542).
4. Introduce poisons into termite galleries in materials which must be left in contact with the ground (chap. 38).
5. Inspect frequently, after repairs, for runways built over the barriers (chaps. 14, 47).

Dry-wood Termites

1. Remove all structurally unsafe materials; destroy all removed material which contains live termites (chaps. 21, 48).
2. Introduce poisons into the termite galleries in materials left in place (chap. 38 and p. 542).
3. Expose material containing termites, such as infested furniture, to lethal temperatures (p. 699).

APPLICATION OF METHODS OF PREVENTING TERMITE DAMAGE

In figure 143 of a hypothetical building are shown practices in construction and maintenance which encourage the attack of subterranean termites. By avoiding such practices much of the damage to buildings occasioned by these termites can be prevented. Many of the faulty methods of construction illustrated apply, in principle, to structures other than buildings and to cellulose-containing materials other than wood.

In chapters 14, 21, 47, and 48 will be found directions for detecting termite damage and recommendations for the prevention of such damage in specific types of structure.

THE USE OF TREATED WOOD *i. e.*, WOOD MADE TOXIC TO TERMITES BY IMPREGNATION WITH CHEMICALS

The varying conditions of use, climate, exposure to contact with the ground, length of service-life desired, cost, and other factors enter into the choice of wood for any specific structure; hence, no single kind of treated or naturally deterrent wood will be selected for every use. Nevertheless, service records of wood impregnated by pressure treatment according to standard specifications (p. 550) with coal-tar creosote have shown that wood so treated will give satisfactory and lasting results under severe conditions of exposure to termite attack (chap. 36), and the Committee recommends the use of such wood, where it is suitable, when the most complete protection against termite damage is desired.

Two materials, coal-tar creosote and zinc chloride, have been largely used in the wood-preserving industry and standardized specifications for their use have been established by the American Wood-Preservers' Association. Some of these treatments thus specified have been made mandatory by the United States Government for all of its purchases of treated wood for various specified purposes. The details will be found in the Federal Standard Stock Catalogue, Section 10, part 5, T T–W 571. There are, however, other preservatives for which no standard specifications for treatment have as yet been established. Some of these preservatives have been proven to be toxic to termites and, in treatments of known poundages, to preserve the wood from attack by them in our laboratory tests. In other cases, as, for example, in that of sodium silicofluoride, the effective poundages will be much less than the minimum recommended poundage in the standard specifications for zinc chloride, because silicofluoride has less solubility than the zinc chloride (chaps. 34, 35). However, the silicofluorides have been shown by our tests to be much more toxic to termites than zinc chloride. Standardized specifications for treatment with these other preservatives must rest upon adequate service records of wood properly treated, with such modifications of previous standards as the nature of the preservative and the process used necessitate.

Service records show that woods treated with toxic chemicals other than coal-tar creosote have proved satisfactory for the length of time they have been used, but in few cases do such service records extend over a period equal to the life to be expected of ordinary structures (chap. 35).

Wood treated with coal-tar creosote by the open-tank method (chap. 35) has an excellent and entirely satisfactory service record for some purposes, especially where sapwood is concerned, but it is not considered to afford adequate protection under the severest conditions.

Results of experiments (chaps. 33, 36, 41) indicate that adequate pressure treatment of wood with certain chemicals renders the treated wood toxic to termites. Other experiments indicate, however, that chemicals which are toxic to termites in certain amounts are less toxic or not toxic in lesser amounts. It is important, therefore, that the wood be impregnated with a sufficient quantity of suitable preservative for the conditions under which it is to be used.

Standard pressure treatment of wood with proper chemicals produces a fairly uniform protective toxic layer of sufficient depth (chap. 36). In synthetic wood products the toxic treatment may be incorporated throughout the piece.

Recent developments in the wood-preserving industry are in the direction of refinement of chemicals used, increased suitability of toxic treatments for light structural members, and a more complete penetration of the chemicals throughout the treated materials (chap. 41).

Wood which is to be chemically treated should be framed (cut to desired shape and size), adzed, or bored, when practicable, *before* treatment. When this is not practicable, the untreated surfaces which are exposed by the framing or fitting operations should be heavily brush-coated with a hot solution of the same or a similar preservative. Instances have come to the attention of the Committee in which bolt holes, spike holes, checks due to the seasoning of the wood, saw-cuts made in framing the lumber, penetration of the treated shell of the timber due to handling with cant hooks or pike poles, and other injuries, have afforded an entrance for termites and decay, thus destroying the value of the protective treatment.

The Committee's experiments have shown that surface treatment of wood by brushing, spraying, or momentary dipping affords varying degrees of deterrence because of varying completeness, depth, and concentration of the toxic layer. Such treatments are by no means so effective and dependable as those by impregnation under pressure according to standard specifications. Termites are skilful in utilizing any weak point in such protective shells, and under laboratory conditions are observed in the absence of untreated wood to attack and penetrate only the thinly impregnated portion to reach the untreated wood within, leaving the thickly impregnated portion untouched, when the two are equally available.

Spray or brush treatments applied to lumber already in place do not protect the wood where it is subject to hidden attack by termites, such as surfaces in contact with foundation walls, and joints of wood members. Spraying with a pressure gun is one form of applying chemicals which has had considerable experimental use. While a pressure gun does force the liquid spray out of the gun under pressure, it does not force it into the wood under pressure; consequently, the value of such treatment can be but temporary at best. Spray treatments on uninfested lumber, when accompanied by other preventive measures and followed by periodic inspections to see that the wood remains uninfested, may be of some value if repeated with sufficient frequency.

One of the first investigations made by the Committee was directed toward the development of a process for treating unseasoned lumber at the sawmill by dipping the lumber in, or running it through, a chemical bath. So far as the Committee has been able to ascertain, no such process has been developed which will give anything more than temporary protection against termite attack. Many of the chemicals proposed for this kind of treatment are soluble in water; hence the protection is soon lost when the lumber is exposed to the weather. The penetration of the chemical into the wood is in most cases very slight, and subsequent seasoning checks expose untreated material to termite and fungus attack. It is believed, however, that this method of treatment will greatly reduce the probability of infestation of lumber by swarming dry-wood termites (chap. 53).

THE USE OF WOOD WHICH IS RELATIVELY UNPALATABLE TO TERMITES

The Committee recommends sound, seasoned heartwood of the less palatable species of wood especially for use above the ground, where protection beyond that which can be obtained by methods of construction hereinafter outlined is desired, or where such methods cannot be used, and where the most complete protection is not required or is not feasible (p. 548).

The palatable attractiveness of wood to termite attack rests upon its inherent food resources. Elsewhere (chaps. 9, 43) we show that invisible fungi occur in the immediate surface of the walls of termite burrows. Capacity to grow such fungi enters into the attractiveness and availability of wood for termite attack. The less palatable woods, while containing such necessary food materials, also contain substances in their extractives which in certain concentrations are toxic, and in less concentration deterrent, alike to fungi and termites. For example, the extractive from freshly felled redwood has been found in certain concentrations, but not in others, to inhibit the growth of bacteria and fungi. The inhibiting effect varies in the extractives from different parts of the tree (Sherrard and Kurth, 1933*a*, or chap. 42).

The sapwood of practically all species of trees is palatable to termites. The heartwood of most species is also to less and varying degrees palatable to termites. The heartwood of certain species, such as the cedars, cypress, and redwood, is less palatable than that of most other species. Such heartwoods are often not attacked, or are less seriously damaged if attacked, especially if other wood is available. It is such species which are referred to herein as less palatable.

In the heartwood of these less palatable woods there is a direct parallelism between the restriction of damage by both termite and fungus and the amount of soluble extractives (chaps. 41, 42). Hawley, Fleck, and Richards (1924) subjected fungus to hot-water-soluble extractives from various woods and report "the relative resistance to decay of the several woods examined can be largely explained by the toxicity of their extractives." They also report, "It is a noticeable fact that, as far as their chemical compositions have been determined, woods that are durable under actual service conditions contain extractives of a peculiar kind in large amounts. The non-durable woods, it is also to be noted, are generally low in such extractives."

When using untreated wood all sapwood should be excluded. Many instances have been observed in which poles, fence posts, and structural timbers of relatively unpalatable wood have been damaged by termites. In many of these cases sapwood has been found present in the piece, or they have been long in service. Untreated sapwood of any species is more readily attacked by termites than heartwood. The presence of untreated sapwood in a structure permits the establishment of colonizing pairs, their persistence throughout their critical first year (chaps. 14, 21), and the spread of colonies into heartwood which might have resisted the initial attack.

The factors affecting the incidence of attacks by wood-destroying fungi have been extensively studied by the Forest Products Laboratory of the United States Department of Agriculture. A classification of woods with reference to their durability as affected by fungus attack has been made and is given in the following quotation (Hunt, 1928*a*, *b*). The investigations of the Termite Investigations Committee show that fungi and termites are intimately interrelated and that the same factors which affect fungi also influence the incidence of damage by termites.

> Wood kept constantly dry or continuously submerged in water does not decay, regardless of sapwood or species. A large proportion of the wood in use is kept so dry at all times that it lasts indefinitely. Moisture and temperature are the principal factors which affect the rate of decay; they vary greatly with the local conditions surrounding the wood in service. When exposed to conditions which favor decay, wood in warm humid areas of the United States decays more rapidly than in cool or dry areas. High altitudes are as a rule less favorable to decay than low because the average temperatures are lower and the growing seasons for fungi are shorter.
>
> The natural decay resistance of all common native species of wood is in the heartwood. When untreated, the sapwood of practically all species has low decay resistance and generally short life under decay-producing conditions. The decay resistance or durability of heartwood in service is greatly influenced by differences in the character of the wood, the attacking fungus, and the conditions of exposure. Therefore a widely different length of life may be obtained from pieces of wood which are cut from the same species or even the same tree and used under apparently similar conditions.
>
> General comparisons of the relative decay resistance of different species must be estimates. They cannot be exact and they may be very misleading if understood as mathematically accurate and applicable to all cases. They may be very useful, however, if understood as approximate averages only, from which specific cases may vary considerably, and as having application only where the wood is used under conditions which favor decay. The following classification of common native species is subject to the limitations mentioned above.
>
> From service records where available, supplemented by general experience, the heartwood of the following species (the species are listed alphabetically and not in order of their relative durability) may be classed as durable even when used under conditions which favor decay: the catalpas, practically all of the cedars, chestnut, southern cypress, the junipers, black locust, red mulberry, osage-orange, redwood, black walnut, and Pacific yew.
>
> Similarly the heartwood of aspen, basswood, cottonwood, the true firs (not Douglas fir), and the willows, when used under conditions which favor decay may be classed as low in

decay resistance, while the heartwood of Douglas fir, red gum, western larch, chestnut oak, southern yellow pine, and tamarack may be classed as intermediate. The heartwood of dense Douglas fir, honey locust, white oak, and dense southern pine may also be classed as intermediate but nearly as durable as some of the species named in the higher durability group. The heartwood of the ashes, beech, the birches, the hemlocks, sugar maple, the red oaks, and the spruces may be considered on the border line between the intermediate and non-durable groups and cannot with assurance be placed wholly in either group.

Results of our experiments (chaps. 41, 42) indicate that heartwood containing high concentrations of natural preservatives is less palatable to termites, in general, than wood of the same species which contains low or medium quantities of such preservatives.

It has also been noted that some very resinous pieces of heartwood from a species of wood which is usually palatable are less palatable to termites than heartwood from the same species which is very low in resin content (chap. 42). The following indicates that such woods react similarly to decay (Hunt, 1928*a, b*):

> The natural preservatives stored in the heartwood may be present in larger amounts in some trees than in others of the same species. Wide differences in this respect may be found even in different parts of a single log, with resulting differences in decay resistance. In the pines and Douglas fir occasional pieces are very resinous or pitchy. Wood thus saturated with pitch or resin is exceptionally resistant to decay and gives very long life in contact with the ground or in other places where conditions favor decay.

CONSTRUCTION RECOMMENDATIONS

One practical way of reducing or eliminating the infestation of wooden structures by termites is to be found in proper methods of construction and repair of buildings. Such methods are applicable through mandatory building codes, and many communities in termite-infested territory are now seeking to provide this mode of protection. The specifications presented below aim to eliminate and protect against the establishment of reservoirs of termite food in the soil or under buildings, and to protect structural materials of wood from the invasion of termites from the soil and, as far as possible, from the settlement of new colonies at swarming time.

The General Recommendations of the Executive Committee, in so far as they relate to (1) methods of construction, (2) building specifications, and (3) statutory building legislation, are incorporated in the following specifications:

SPECIFICATIONS FOR PREVENTION AND CONTROL OF DAMAGE IN BUILDINGS BY TERMITES FROM THE SOIL

(a) All stumps and roots in the ground to be occupied by the building shall be removed.

(b) All foundation walls and piers shall be of concrete or of masonry laid in Portland cement mortar, and shall extend at all points at least six (6) inches above the finished grade. Masonry or concrete foundation walls shall extend at least as high as the top of any adjacent concrete or masonry slab which is supported by either natural ground or an earth

fill. All foundation walls shall be reinforced with not less than two (2) steel rods, three-eighths (3/8) inch in diameter, placed not more than four (4) inches below the top of the wall. Such reinforcing shall be continuous throughout the length of every wall and around all corners. The length of the lap in every splice shall be not less than forty (40) times the diameter of the rod.

(c) A termite barrier, as described in section *(e)*, shall be installed in the building, and all wood between such barrier and the ground shall be No. 1 common or a better grade of lumber which is impregnated by pressure treatment with a final retention of not less than eight (8) pounds of No. 1 grade of coal-tar creosote per cubic foot of wood, the grade of creosote and the method of treatment being in accordance with specifications of the American Wood-Preservers' Association; or such wood shall be No. 1 common or a better grade of lumber which is impregnated by a pressure treatment with such other equivalent preservative and equivalent method as may hereafter be approved. Such wood shall be completely framed before treatment whenever this is possible, and when it is not possible, the surfaces exposed by cutting after treatment shall be thoroughly coated with at least two coats of hot coal-tar creosote or other equivalent preservative.

(d) Openings through foundation walls or exterior walls shall be provided for cross ventilation of the space below the first floor in every building in which the first floor is of wood frame construction. There shall be one opening at least two (2) square feet in net area within five (5) feet of every corner of the exterior walls of the building, and there shall be two (2) square feet of opening for each twenty-five (25) lineal feet, or major fraction thereof, of exterior wall, provided, however, that such openings need not be placed in the front wall of the building. Where it is impossible to obtain such ventilation, all floors lacking subfloor ventilation and their supporting structures shall be constructed of concrete, masonry, or wood pressure-treated as specified in section *(c)*.

(e) The termite barrier specified in section *(c)* shall be so constructed as to completely cut off all access of termites from the ground to all untreated wood above said barrier. The barrier shall be made of material impenetrable by termites, such as reinforced concrete, non-corrosible metal, metal lath and plaster, or tongue and groove or shiplap wood pressure-treated as specified in section *(c)*. All wood between this barrier and the ground shall be pressure-treated as specified in section *(c)*.

Floor joists shall have a clearance of not less than eighteen (18) inches between the joists and the surface of the ground underneath. The ground underneath floor joists shall be leveled or smoothed off so as to maintain a reasonably even surface under the entire area covered by the floor joists.

(f) Wood laid on concrete which is in contact with the earth, such as sleepers, joists, subflooring, and attendant construction, shall be impregnated with an approved preservative, as specified in section *(c)*.

(g) The ends of wood members entering masonry or concrete shall not be sealed in, but shall be provided with recesses or with metal wall boxes affording an air space at the end of the piece of not less than one (1) inch at each side of the member, or all surfaces of the member within one (1) foot of the end shall be painted with at least two (2) coats of hot coal-tar creosote or other approved wood preservative, unless the members as a whole are impregnated with coal-tar creosote or other approved preservative as specified in paragraph *(c)*.

(h) All wood forms which have been used in placing concrete, if within the ground or less than eighteen (18) inches above the ground, shall be removed by the contractor. No waste wood shall be buried by the contractor in any fill, or otherwise.

(i) Before completion of the building, all loose and casual wood shall be removed by the contractor from direct contact with the ground.

(j) For ground treatment under and around dwellings the following chemicals may be used: saturated aqueous solution of copper sulfate or of sodium fluosilicate; or a saturated aqueous solution of borax; or full-strength crude liquid orthodichlorobenzene; or crystalline paradichlorobenzene.

(k) In case a building material containing arsenic or other poison is used in a building, such material shall carry a permanent label on every square yard of the material, stating: "Poisoned with arsenic (or other substance)." In case the soil under or around a dwelling has been treated with arsenic or other poison, a permanent sign shall be installed, saying: "Poisoned with arsenic (or other poison)."

These specifications, if properly carried out, are regarded as being adequate to protect buildings from damage by termites coming from the soil.

CHAPTER 47

INSPECTION AND MAINTENANCE

BY

CHARLES A. KOFOID *and* G. EDWARD CHASE

Adequate inspection for termites and termite damage requires a knowledge of the habits and appearance of these insects in *all* of their stages and castes, of the nature and appearance of their workings, and of the locations in buildings most favored in settlement and attack. The inspector should also be familiar with the *different species* of termites, their characteristic modes of work and differential locations in buildings. It is also important that the inspector have a knowledge of building construction and of methods of detecting and exposing termite attack in the various locations in the structure (chap. 48). A study of this report by the termite control operator, contractor, or house owner, and field experience in searching for evidence of termite attack in various types of structures, will be helpful in inspection and maintenance.

The expert in termite control must also have a general knowledge of the many aspects of this particular specialty. He should have not only a specialized knowledge of termites and other wood-destroying insects and fungi, but also a general knowledge of good and bad practices in construction, the chemical, physical, and mechanical properties of wood, the properties of materials toxic to insects, and the principles of insect pest control.

While all of these qualifications are not essential to the mere discovery of termites or termite damage in an individual structure, they are all essential if the most economical and permanently effective methods of termite control for all types of structures is the objective sought.

Prior to the formation of the Committee in 1928 there were but few termite control operators regularly engaged in the business in California. Three years later there were approximately one hundred such operators. As might have been expected, this group included individuals of varying preparation and efficiency. In August, 1931 the Bureau of Entomology of the United States Department of Agriculture took occasion to warn the public against the methods being employed by some operators who sought to create new business by arousing undue fear in the public mind as to the termite problem. Such a warning was justified.

Systematic and repeated inspection is essential to the permanent success of any plan for prevention of termite damage or its recurrence, and the success of the plan will depend on the adequacy and the seasons of such inspections. The structures and adjacent premises where termite attack may be expected should be inspected thoroughly at least every six months for evidences of termite damage. At every swarming season (chaps. 14, 20, 24) inspections should be made at the exact time of day and under weather conditions favorable for detection of emerging alates for evidences of regions of infestation. Every home owner should avail himself of this opportunity. Inspections at six-month intervals will provide a check on the adequacy of the methods used in construction or repair before any great amount of damage by termite attack can be done. When no periodic inspections are made, unless a very thorough repair and prevention job is done, future damage is not likely to be discovered until the cost of the subsequent repair job greatly exceeds the cost of adequate inspection.

There is a trend toward the development of combined control and inspection service, backed in some cases by a bond carrying financial guarantees of the responsibility of the operator and the effectiveness of the service, which the Committee believes will ultimately do much to insure adequate inspection and control and thus limit termite damage. Such service is, of course, dependent on the efficiency and reliability of the operator and the soundness of the bonding company. As such service is extended, termite damage in the community will progressively decrease.

The desirability of bonding termite operators is clearly shown in reports which have come to the Committee's attention during the past three years. Work done to repair existing termite damage can usually be readily examined and its sufficiency determined, but the efficiency of work done to prevent future termite damage is not so easily determined. Where an operator obligates himself financially to prevent termite damage over a period of years he will find it advisable to do a thorough job the first time.

This Committee is of the opinion that the development of competent and conscientious termite control operators and their employment by the public in a consulting capacity is an essential step toward the solution of the termite problem. At the same time, it is recognized that such consulting services will be generally available only in the larger centers of population, for some time, at least.

Where inspection by competent operators is not possible, a systematic inspection by the owner of the property, based on information contained in this report, will at least tend to minimize future termite damage if followed up with necessary maintenance and preventive measures. As an aid to the home owner, it is suggested that chapters 46 and 48 be given particular study before such an inspection is made.

PREVENTIVE MEASURES WHERE INSPECTION IS IMPRACTICABLE

Relatively permanent preventive measures should be used in all cases where systematic inspection of the structural members to be protected is not practicable. Such members as fence posts, piling, bulkheads, and any parts of wood members which are inaccessible for inspection should have more adequate protection from termite attack than members whose parts can be inspected at frequent intervals.

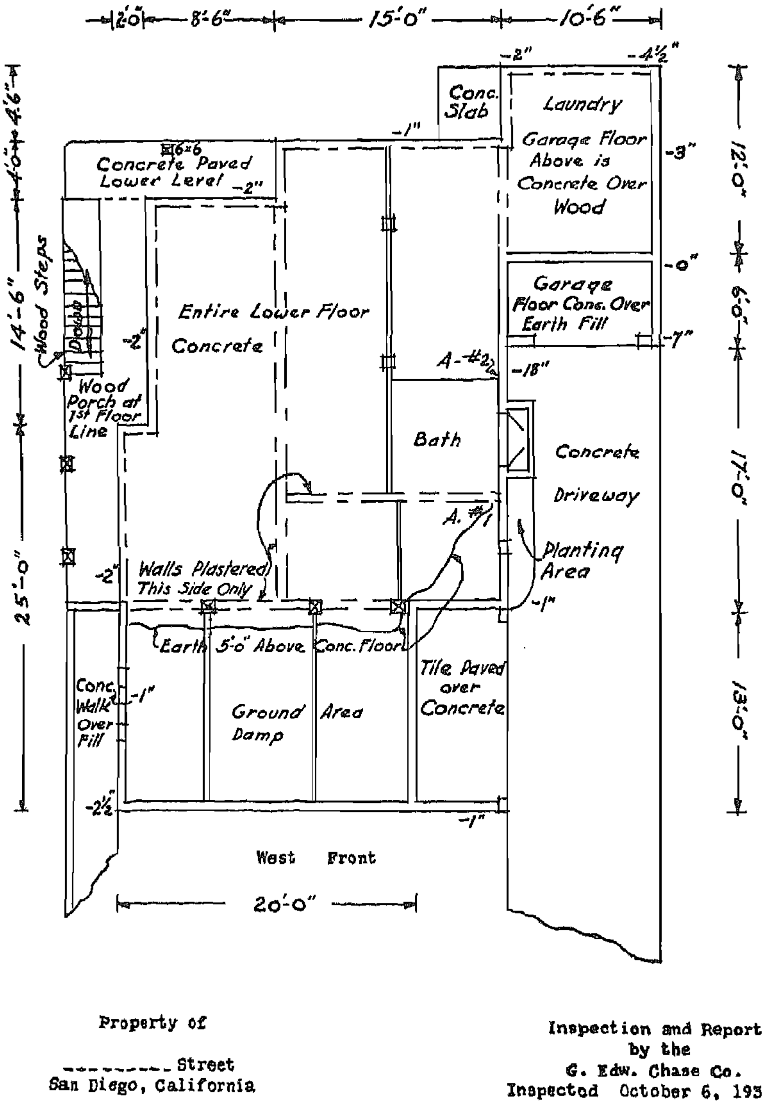
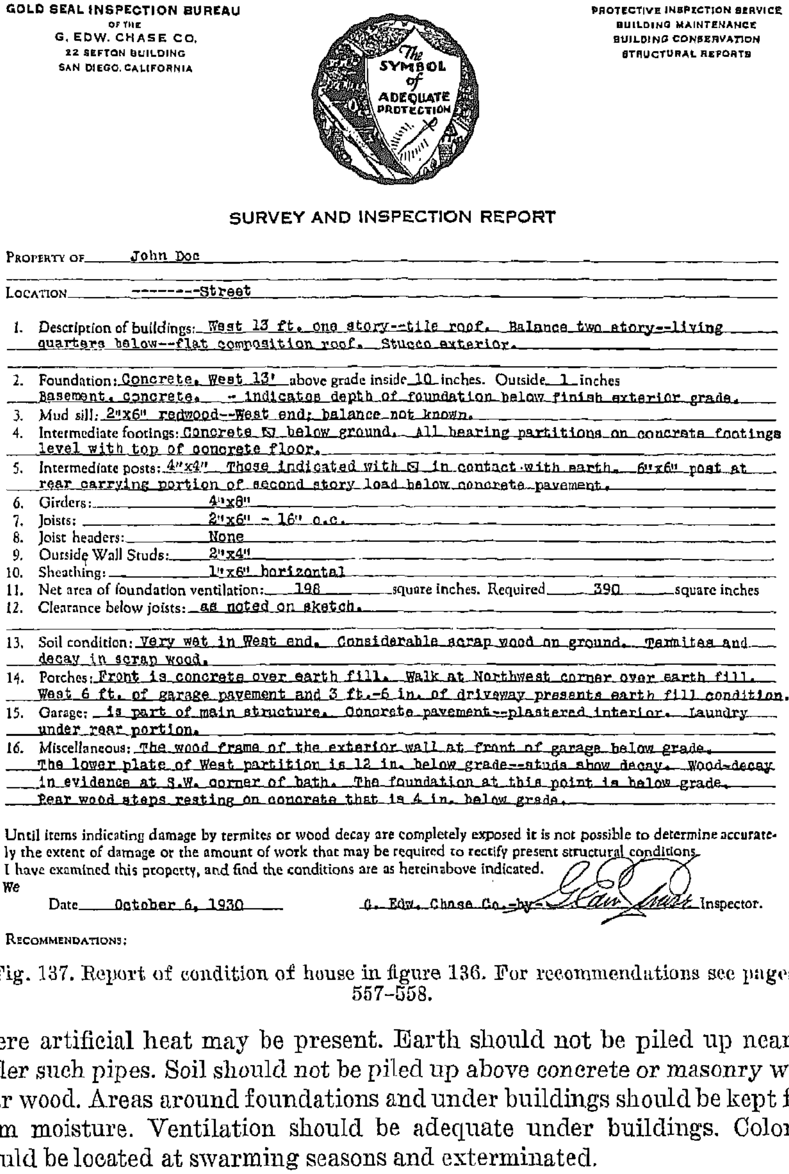


Fig. 136. Floor plan accompanying "Survey and Inspection Report."

All structures and premises should be maintained in a manner which will discourage termite attack. Good housekeeping pays dividends in termite control, as well as in many other ways. Its benefits in prevention of fire and decay are well known. All rubbish, such as papers, casual wood, sawdust, discarded clothing, boxes, trunks, and similar items should be kept from contact with the ground. Particular vigilance should be used in inspection in areas near fireplaces, around steam pipes and hot water pipes, and in all other places



GOLD SEAL INSPECTION BUREAU
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22 SEFTON BUILDING
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The SYMBOL of ADEQUATE PROTECTION

PROTECTIVE INSPECTION SERVICE
BUILDING MAINTENANCE
BUILDING CONSERVATION
STRUCTURAL REPORTS

SURVEY AND INSPECTION REPORT

PROPERTY OF John Doc

LOCATION --------Street

1. Description of buildings: West 13 ft. one story--tile roof. Balance two story--living quarters below--flat composition roof. Stucco exterior.
2. Foundation: Concrete. West 13' above grade inside 10 inches. Outside 1 inches Basement. concrete. - indicates depth of foundation below finish exterior grade.
3. Mud sill: 2"x6" redwood--West end; balance not known.
4. Intermediate footings: Concrete ☒ below ground. All bearing partitions on concrete footings level with top of concrete floor.
5. Intermediate posts: 4"x4" Those indicated with ☒ in contact with earth. 6"x6" post at rear carrying portion of second story load below concrete pavement.
6. Girders: 4"x8"
7. Joists: 2"x6" - 16" o.c.
8. Joist headers: None
9. Outside Wall Studs: 2"x4"
10. Sheathing: 1"x6" horizontal
11. Net area of foundation ventilation: 198 square inches. Required 390 square inches
12. Clearance below joists: as noted on sketch.
13. Soil condition: Very wet in West end. Considerable scrap wood on ground. Termites and decay in scrap wood.
14. Porches: Front is concrete over earth fill. Walk at Northwest corner over earth fill. West 6 ft. of garage pavement and 3 ft.-6 in. of driveway presents earth fill condition.
15. Garage: is part of main structure. Concrete pavement--plastered interior. Laundry under rear portion.
16. Miscellaneous: The wood frame of the exterior wall at front of garage below grade. The lower plate of West partition is 12 in. below grade--studs show decay. Wood-decay in evidence at S.W. corner of bath. The foundation at this point is below grade. Rear wood steps resting on concrete that is 4 in. below grade.

Until items indicating damage by termites or wood decay are completely exposed it is not possible to determine accurately the extent of damage or the amount of work that may be required to rectify present structural conditions.
~~I~~ We have examined this property, and find the conditions are as hereinabove indicated.

Date October 6, 1930 G. Edw. Chase Co.-by-G. Edw. Chase Inspector.

RECOMMENDATIONS:

Fig. 137. Report of condition of house in figure 136. For recommendations see pages 557-558.

where artificial heat may be present. Earth should not be piled up near or under such pipes. Soil should not be piled up above concrete or masonry walls near wood. Areas around foundations and under buildings should be kept free from moisture. Ventilation should be adequate under buildings. Colonies should be located at swarming seasons and exterminated.

AN EXAMPLE OF A THOROUGH INSPECTION

As an example of the results of adequate inspection there are shown the floor plan (fig. 136) and record of inspection (fig. 137) of a building in San Diego, California, together with the foreman's report of conditions disclosed during the progress of the work and the steps taken to repair existing damage and prevent further damage. The house was thirty-eight months old at the time of inspection. The actual damage due to subterranean termites was of no consequence, although five separate areas of infestation were found at scattered points. In submitting this data for inclusion in this report, the president of the company doing the work stipulated that the following statement be made:

> The report shown herewith is an indication of the progress that has been made by the Termite Investigations Committee; for it was through cooperation with the Committee that our company was enabled to obtain the information and knowledge necessary to develop the Survey and Inspection Report as well as other services which are considered essential for the protection of the home owner.

FOREMAN'S REPORT OF CONDITIONS DISCLOSED DURING THE PROGRESS OF OUR WORK

The exterior earth in many places is above the top of the concrete foundation indicated by the *minus signs on sketch.*

The exterior earth along the west wall should be lowered to a point not less than 3 inches below top of concrete foundation. The mudsill along this wall should be drilled and treated, as it is very wet, although there is no evidence of wood decay.

It is impractical to lower the exterior grade along the north and east walls. A 3-inch concrete protection wall is recommended in these areas. The top of the protection wall should be 8 inches above finish grade, and should be provided with ventilating openings.

The outside wall of the foundation in area No. 1 is undermined. The loose earth should be removed and a reinforced concrete wall 3 feet long should be placed to properly support the foundation wall above.

From inside indications it is apparent that the foundation at area No. 2 is stepped down and is approximately 18 inches below grade. This area should be opened from the outside to ascertain the extent of damage, if any, and this condition should be corrected by raising the foundation wall or by placing a concrete protection wall 3 inches in thickness on the exterior.

The exterior grade should be lowered in any area not mentioned above, or the existing conditions corrected either by raising the foundation or placing 3-inch concrete protecting walls.

The loose earth should be lowered around three footings *X* in west area, exposing concrete not less than 3 inches in height. The bottoms of the posts and footing blocks should be drilled and properly treated if found to be sound. If the timbers are found to be decayed, new posts and footing blocks, properly treated, should be used. Two additional pre-cast concrete footings 12 inches × 12 inches × 12 inches should be placed under the two girders in west area to correct deflection. The posts on the exterior indicated as *X* should be on concrete, the tops of which should be not less than 6 inches above grade.

The westerly end of the two girders should be drilled and properly treated, as same are below exterior grade and are very wet.

The ventilation in west area should be increased by placing three vents in west wall.

All wood and other débris should be removed from the ground under the structure. A 3-inch tile drain should be placed along the west wall of the finished portion after the loose earth has been removed. This drain should be carried through the concrete wall and should extend to the edge of the canyon.

The front porch, the area at the northwest corner under the sidewalk, and the west 6 feet of the garage pavement present earth-fill conditions and should therefore be properly sealed.

There is no evidence of wood decay in these areas at present; however, the sealing is suggested because of exterior earth contact and the extremely wet condition of the structural members.

The wood structure of the plastered wall to the entrance of the garage is below grade, and although there is no exterior evidence of wood decay, it is recommended that these walls be opened, all below grade removed, and the concrete foundation raised to a point 4 inches above grade.

The lower plate of the west partition is from 8 to 12 inches below grade. Portions of the plate and the lower ends of the wall studs show signs of decay. The wood plate, wall studding and any wood lath showing signs of wood-rot infection should be removed and replaced with new, properly treated material.

The grade should be lowered at the lower end of the rear steps to a point 3 inches below the top of the concrete foundation; otherwise the lower step should be made of concrete and should be of sufficient width to support the stair stringers.

STEPS TAKEN TO REPAIR DAMAGE AND PREVENT FUTURE DAMAGE

Sealed 19 lineal feet of front porch from below.

Drilled and treated 9 lineal feet of mudsill from porch to concrete curbed light well and placed small section of protection wall in corner by light well where foundation was stepped down.

Cut 3 new vents under front of house, drilled and treated mudsill, vertical sill and ends of two girders along west wall.

Raised concrete foundation wall for 14 lineal feet at northwest corner. Top of foundation is now 4 inches above top of concrete sidewalk. Placed new mudsill on top of the new wall.

Placed a concrete pier, footing block and post under center of both girders over ground area at front of house.

Replaced the infected studs in the wall of bathroom on lower floor. Placed a reinforced concrete wall from the corner of this room to the inner corner of foundation at front porch line. This wall ties into and runs under main foundation wall at both points of intersection. Earth was placed behind the concrete wall and the area on top was paved to be used for storage space.

Placed 3-inch tile drain west of wall running from new foundation wall to the exterior wall on the north.

Removed the earth along the entire east face of the earth bank and left same with a two-to-one slope. The tile drain was extended through the outside wall and connected with 20 lineal feet of cast iron pipe extending from foundation wall through the planting area, so it would drain over the side of the hill.

Drilled and treated the studs and mudsill along the west side of the wall to the finish portion. This material had been in contact with the earth and was very wet, but it was not necessary to replace any of it.

Removed concrete slab at the west end of garage, exposing the wall to the laundry room. Removed earth along house wall from concrete curbing to light well to wall of laundry room. Opened wall along this section and treated the wood structure showing signs of termites. Built a concrete tunnel along here for ventilation and annual inspections. Access to tunnel through loose slab section in garage floor. Paved bottom of tunnel with concrete and placed a 4-inch cast iron drain across under the garage and through the outside wall.

Treated mudsill on wall of laundry room damaged by subterranean termites, and used galvanized iron to provide ventilation from the tunnel to a small vent in the outside of garage wall.

Raised foundation wall of garage at outside corner and removed the decayed studding and wall sheeting. The section of the garage floor was replaced.

Constructed 8 lineal feet of 3-inch protection wall along south wall of garage, as it was impossible to lower the exterior grade, the garage being 1 foot from property line.

Constructed 54 lineal feet of protection wall extending from corner of laundry room to wall under end of concrete sidewalk at front of corner of house. Ventilators were placed in this wall. The 3 inch × 4 inch mudsill and the bottoms of the wall studding were all drilled and dry treated, and the exterior surfaces of this material were wet treated.

Rear wall of laundry room was found to be infected with wood decay. Foundation was raised 12 inches, and all wood in the wall, including wood lath, was removed to window height and replaced.

Picked up three posts under side wood porch on concrete piers and leveled up the section of concrete walk at the bottom of wood steps. Could not lower grade at steps, so placed concrete step and carried stair horses on same. Repaired wall of lower floor bath where plaster had become loosened from dampness in the concrete wall.

CHAPTER 48

BUILDINGS

BY

A. C. HORNER, EARL E. BOWE, WALTER PUTNAM, and G. EDWARD CHASE

HISTORY OF TERMITE DAMAGE TO BUILDINGS ON THE PACIFIC COAST

It is not definitely known how long ago termites first put in an appearance in buildings on the Pacific Coast. It was not until the growth of cities and towns became active about 20 years ago that the presence of termites in buildings attracted attention. From records available it is indicated that cognizance of termite damage was taken in southern California in 1915. In 1918 two buildings in Pasadena were repaired due to damage by subterranean termites.

On the Pacific Coast, official notice by a governmental body of termite damage in buildings was first taken by the Building Department of the City of Pasadena in 1926. In that year termite infestation was noted, during alterations, in a garage building having brick walls, wood posts and roof trusses, and a concrete floor. Investigation showed that subterranean termites had gone fourteen feet up the brick wall, then through the lime mortar, and had worked in the posts for a distance of four to five feet above the floor. As a direct result of this case investigations were made of public and semi-public buildings in the city to determine the presence and extent of termite damage. Available information from governmental sources was studied. One man was assigned the task of inspecting stores, churches, theaters, and municipal structures. Even with his limited knowledge he found many cases of damage, which were subsequently ordered repaired. This investigation called forth criticism from local agencies, which felt that unfavorable widespread publicity would ensue, and an attempt was made to stop the inspections. However, the city's governing board decided that the work was of sufficient economic value to justify its continuance.

Late in 1926 termite damage in other communities came to light. Interest in the subject of preventing further infestation and correcting damage already done increased and became more general. This interest was partially responsible for hastening the formation of the Termite Investigations Committee.

EXAMPLES OF TERMITE DAMAGE

FROM THE RECORDS OF THE COMMITTEE

There is no "typical example" of termite damage to a building. An analysis of 1,000 cases of subterranean termite attack which are included in the records of the Committee was made by Mr. A. L. Pickens, biologist for the Committee. In his report of these cases he says, in part:

In the accompanying table [Table 50] the first 1,000 cases of subterranean termite attack, diagnosed with sufficient accuracy to warrant use in a scientific table, have been assembled and classified with a view to arriving at preventive measures. The sources of information have been general for the western states and rather general for man-made structures, and the effort has been to designate the chief causes of infestation rather than to state the relative importance of various causes of attack.

TABLE 50

DIAGNOSIS OF 1,000 CASES OF ATTACK BY *Reticulitermes* IN THE WESTERN STATES

1. Direct ground contacts		768
2. Concrete foundation trouble		92
Form boards left	22	
Foundations level with ground	8	
Foundations slightly above ground	23	
Foundations over one foot high	15	
Floors laid on concrete	9	
Cracks in concrete	9	
Timbers stuck into or through concrete	5	
Partial removal of concrete	1	
	92	
3. Doorsteps affording ground contact		28
4. Landscaping and earth-banking		18
5. Failure of treated woods		17
6. Earth-filled terraces, stoops, etc		13
7. Shingling too near ground		13
8. Runways over brick foundations		10
9. Stumps left beneath houses		7
10. Faulty, low additions to houses		6
11. Leaking of water on wood		4
12. Runways through old adobe walls		4
13. Attacks on boxes, cartons, etc		4
14. Attacks on records, papers, etc		4
15. Imperfectly joined subterranean vaults		4
16. Runways over stone foundations		2
17. Infestation from undetermined source into roof		2
18. Infestation from undetermined source into basement shelving		2
19. Runways through macadamizing		1
20. Plumber- or gopher-made earth piles		1
		1000

No stumps are found under the houses in a city commendably careful of the understructure of its dwelling houses, but they may be exceedingly common under flimsily built residences thrown up by the fly-by-night type of speculative builder who builds with the idea of selling out and moving on within a short while.

It will be noticed that much more trouble is experienced with concrete foundations than with either brick or stone. These figures are capable of misinterpretation unless one bears in mind that the number of brick and stone foundations is very small compared to that of concrete. However, it is well to remember that brick and stone are usually bound with a good grade of mortar, every inch of which is troweled under the mason's eye as it is put in place, and the wall is leveled off and permitted to dry before the mudsill is placed.

Cement, on the other hand, is often dumped in by the barrowful and not tamped sufficiently to bind pebbles and cement, so that huge cavities are left, large enough to serve as termite roadways, and even as broad chambers, without the termite having to excavate them; furthermore, the mudsill is often placed in a faulty manner. Some carpenters, before the top layer of cement is dry, hasten to drive huge spikes into what is to serve as the lower side of the mudsill, after which the timber is dropped onto the top of the foundation with the spikes plunging into the wet cement. When the whole has dried and the forms are removed, the mudsill is often found embedded in a water-holding trough formed by the splashing up of the cement for a short distance at the lower side of the mudsill, which dries in that shape. The close bond between timber and concrete tends to keep the timber damp, thus inviting attack by both termites and fungi.

Upon analyzing the causes of trouble with concrete, we find that most of it arises from foundations level with the ground, or only slightly above. Termites, however, even in northern California, may build runways over high concrete foundations, and in several instances have been known to build over walls nine, twelve, and even fourteen feet in height. It is probable that such cases, if analyzed after extensive excavation, would be found to result from an abundant supply of form boards left in the soil beneath, wherein the termites have multiplied sufficiently to permit such extensive runway building. Wood floors laid over concrete are susceptible to attack either through cracks or through openings for water and steam pipes. Cracking of concrete foundations accounts for other infestations.

The custom of permitting upright studs and columns to rest in cups in concrete floors, or to project entirely through a later addition of a concrete floor, and to come in contact with the ground beneath, is highly dangerous, especially if a good portion of the house above rests on such a stud or column. Under the first condition any moisture placed on the floor in washing or otherwise tends to collect in the cup and disintegrate the lower end of the column either by decay or by termites finding entrance through cracks that form as a result of localized weight. If the timber rests on the ground beneath, we have a camouflaged ground contact, and termites, by means of constant activity and wide-ranging exploring parties, easily reach such by traveling under the concrete. Rat-proofing, laid down properly and in a smooth sheet, is a good termite preventive, especially so since it presupposes the cleaning up of all stumps and débris under the house; but when placed on lazily over and around wooden columns and in some cases, to avoid a minimum excavation, even spread over mudsills and unremoved forms that are in contact with the ground, it becomes a liability.

It is a rash lawyer who attempts to find a loophole through the law of necessity. However, there is a curious quirk in the psychology of builders and home-owners that constantly seeks to interpret "ground contact" in the manner of a legal quibbler. In the minds of these people only a horizontal ground contact matters, and a vertical surface of earth or soil against a wooden wall never counts as dangerous, while others seem to feel that so long as the actual foundations are sufficiently high no end of ground-touching steps, stoops, porches, etc., matters much; hence the long list of infestations from wooden steps too close to the ground, stucco and wood walls against which earth has been banked, earth-filled terraces, and ground-contacting porches, and lean-tos built on the upper side of otherwise well built homes, and even partly buried in the ground or thrust against excavated banks sloping up the hill from the house.

Another curious oversight that frequently occurs is the nailing on of shingled side walls in such a way that the lower tier is in contact with the ground, thus offsetting the benefits (from a termite-damage-prevention standpoint) of the concrete foundation that may have been properly placed. The small cracks between shingles placed on the outside walls afford splendid runways at a minimum of labor on the part of the insects, and alates have been known to swarm in the second story of a building so constructed.

Stumps left under the house, particularly after being cut green and immediately shaded, furnish a good breeding place for termites from which they can build or otherwise secure entrance into the house over the stump. Such a condition usually indicates a cheap and careless type of excavation. Not only should stumps be removed before building, but the soil should be excavated on a level until the foundation stands free and clear not less than 12 to 18 inches above the highest point in the soil beneath the floor. The contractor who leaves stumps under a dwelling often leaves blocks, chips, and other débris under the floor after the building is finished, and these are a fruitful source for breeding a colony large enough to do considerable damage to the house.

SAMPLE CASES OF TERMITE DAMAGE REPORTED BY A TERMITE CONTROL OPERATOR

In order to illustrate some of the more important precautions which must be taken to prevent subterranean termite damage, several actual cases of repair work, as reported by a southern California termite control operator, are described below.

Case No. 1. This was a building five years old, of apparently good construction, where there was no external evidence of termite damage. In tracing down the origin of a flight of subterranean termites, certain structural conditions were brought to light which might eventually have resulted in a serious condition if the damage already done by both termites and wood decay had not been discovered.

The structure mentioned was of mill type construction having a full basement 12 feet in height and a first and second story. The exterior walls below the first floor line were concrete, and those of the first and second story were brick. The basement floor was a good grade of concrete, well laid, and had a wearing surface 1 inch in thickness. Two rows of wood columns 10 inches × 12 inches and 12 inches × 12 inches supported the wood girders carrying the first floor load. These wood columns were exposed in the basement area, and from outward appearance were in satisfactory structural condition.

A sheet of oilcloth was used to incase one of the columns and extended 4 feet above the floor line. A group of swarming subterranean termites was noted coming from the upper edge of the oilcloth. The oilcloth was removed, disclosing tubes and some damage on the surface of the wood column, although in no section did the work of the termites exceed 1 inch in depth.

A ¼-inch hole was drilled in the base of the column for the purpose of inspection, and it was found that the bottom of the wood column was resting on a steel plate 12 inches below the top of the concrete floor. An examination of the column showed conclusively that the point of infestation was below the surface of the concrete floor. The concrete floor slab was 5 inches thick, leaving 7 inches of the lower portion of the wood column exposed to earth contact.

The remainder of the wood columns, 16 in number, were then examined and a similar condition was found to exist at the bottom of each column. The amount of wood exposed to earth contact varied from 2 to 7 inches. All but one of the columns were badly damaged by termites or wood decay. Seven of

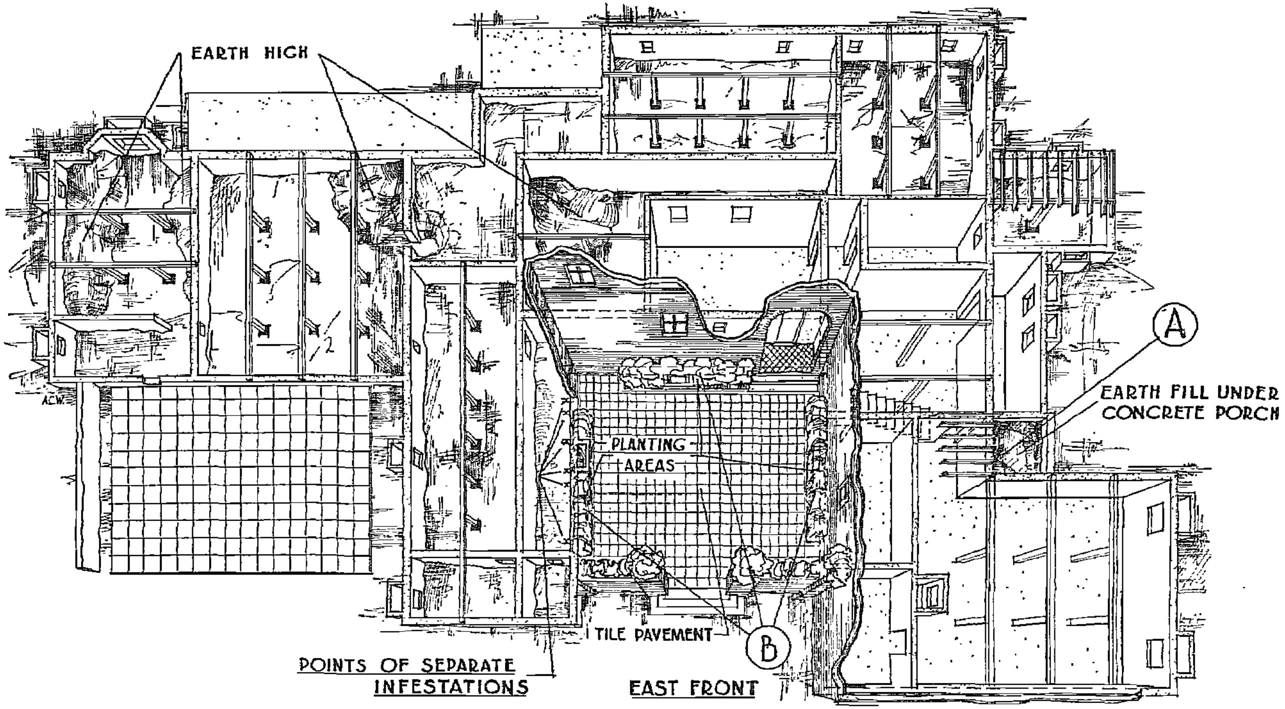
EARTH HIGH
EARTH FILL UNDER CONCRETE PORCH
A
PLANTING AREAS
TILE PAVEMENT
B
POINTS OF SEPARATE INFESTATIONS
EAST FRONT
A.C.W.

Fig. 138. Sketch of house in case No. 2, showing damage by subterranean termites.

the columns were more than one-half destroyed where exposed to ground contact, although there had been no indication of settlement of the structure above.

The damage in the center of some of the columns extended 1 foot above the surface of the concrete finish floor. The lower portions of all wood columns were removed and replaced by concrete piers which were carried up at least 6 inches above the finish floor. Steel plates were inserted between the bottoms of the wood columns and the new concrete footings.

The labor and material necessary to correct the faulty structural conditions mentioned amounted to approximately $310. The additional cost of properly constructing the piers at the time the building was erected would not have been in excess of $20.

Case No. 2. An interesting case of apparently good construction was furnished by this two-and-one-half-story frame residence, the exterior walls of which were veneered with brick. This building was erected in 1912, added to and remodeled in 1917. It is valued today at approximately $65,000. Although the building appeared to be well built, many structural conditions requiring attention were found.

The area indicated at *A* (fig. 138) was covered by a concrete porch slab which was level with the finish floor of the adjacent portion of the building. The ceilings in the basement areas adjacent to the porch were plastered, and although there were no external evidences of damage, it was considered advisable to remove the plastering on the ceiling next to the outside wall for the purpose of ascertaining the conditions existing in the wall. A small section of the plaster was removed, exposing the mudsill, the ends of the first floor joists and the bottoms of the 2 inch × 6 inch outside wall studs. The structural wood members in this section were found to be heavily infested with subterranean termites and considerable damage had been done to the wall studding and to the 3-inch sill (*A* in fig. 138; fig. 139*A*).

The concrete porch slab was removed and was found to be 4 inches thick, and as it was level with the finish floor, the earth fill under the slab was 8 inches above the concrete foundation, and the wood structural members were separated from the earth fill only by the brick veneer.

In the walls adjacent to the planting areas (*B* in fig. 138; 139*B*) the space between the floor joists was filled with common brick from the top of the concrete foundation to the under side of the subfloor. The brick was laid directly on the wood plate and incased the bottoms of the 2 inch × 6 inch wall studs. Subterranean termites had entered through the lime mortar joints and had seriously damaged the sill and the bottoms of the wall studs. The outer end of the floor joists had been damaged, although the damage was confined principally to the outer 2 inches. It was unnecessary to replace any of these joists. Some of the wall studs were damaged at the lower end.

In correcting the conditions at point *A* a trench was made in the earth fill under the concrete slab along all sides of the building in contact with the porch. This trench was then filled with a very dense concrete, which effectively separated the brick veneer as well as all wood framing members from

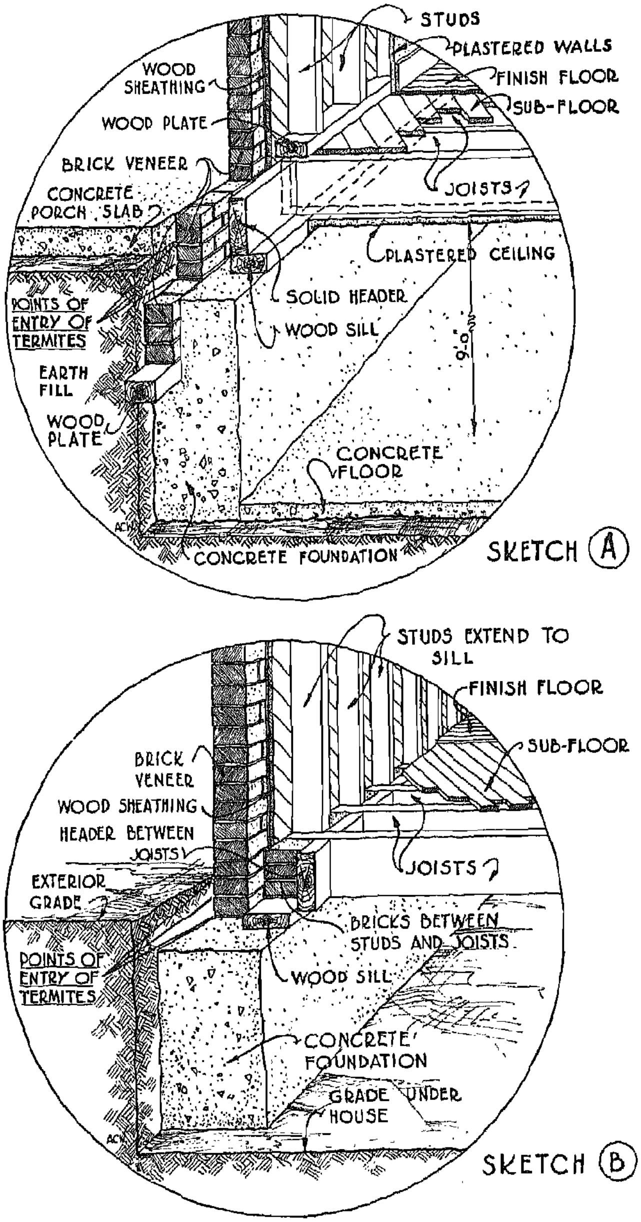

Fig. 139. A. Sketch of part of house in figure 138 at point A.
B. Sketch of part of house in figure 138 at point B.

contact with the earth. The concrete seal as placed was kept 1 inch from the wood sill and the bottoms of the wall studding, thus preventing any future damage from moisture from either above or below the concrete slab.

Conditions at point *B* were similar except that there was no concrete porch slab to complicate matters. Termites obtained access to the interior woodwork through the mortar in the joints of the brickwork. Either a different mortar or the lowering of the earth at this point would have prevented termite damage.

When brick is used as a veneer, care should be exercised to specify proper materials for the lower mortar joints, and the brick veneer should be placed directly on the concrete foundation wall. A rich Portland cement mortar should be used for this work; otherwise it will be possible for subterranean termites to enter the structure undetected, for, as shown, subterranean termites are able to penetrate the average mix of lime mortar. This also applies to the use of tile as a veneer over wood.

It was necessary to correct other structural conditions in this house. The earth under the first floor joists was too high in many places, and it was considered advisable to remedy this condition even though termite infestation or decay was not present in the adjacent woodwork. The total cost of the work of correction in the areas mentioned was over $200. If proper attention had been paid to structural details at the time of building, this expenditure would have been unnecessary. This case shows the necessity for a careful examination of property based more upon structural conditions than upon evidence of damage.

This case also shows the necessity for extending a concrete foundation at least 6 inches above finish grade line even though brick or tile is used as an exterior veneer. Studding and floor joists should not be incased in brick, as damage due to decay may result.

Case No. 3. This three-story building with brick exterior walls was built in 1912. An examination of the property showed signs of subterranean termite infestation along the east and south walls. The evidence of the infestation was principally at the first floor joist line. Comparatively few tubes were found extending from the ground under the structure to the floor joists. The greatest amount of infestation was next to the outside walls of the building. The termites entered from the outside through the lime mortar joints. Continuous intermediate footings were used instead of individual intermediate pier footings. These intermediate walls were carried to the under side of the joists, no girders being used.

No plate or sill was used on the outside walls; the joists were laid directly on the wall and the ends were bricked in. The joists were 2 inches × 12 inches, spaced 16 inches on center with 2 inch × 12 inch headers between the joists, placed directly in contact with the inner surface of the brick walls. The exterior earth grade was approximately level with the finish floor line; therefore, the lower edge of the floor joists was approximately 1 foot below exterior earth grade. It is interesting to note that with the floor joists below grade and solidly bricked in and subject to moisture from the exterior there was no evidence of wood decay.

This case is of particular interest in that there were no external evidences of subterranean termite infestation in the floor joists beyond the headers. Nevertheless, upon investigating the conditions in the interior of the joists, several were found to be so badly damaged that it was necessary to replace them. The damage in some of the joists extended to the first intermediate bearing wall 12 feet from the outside wall, and some of the joists were so badly damaged that practically no structural value remained.

The solid headers were removed from between the ends of the floor joists at the outside wall for the purpose of future inspection and observation. It was realized that there might be future infestation from the outside. Therefore, it was recommended that the structure be carefully watched and that such treating as might be necessary be done from time to time as indications of infestation were found. The treatment recommended was to drill and treat internally as well as externally the ends of all floor joists in the infested areas. The cost of the work considered necessary at this time was $107, which was remarkably low considering the age of the structure and the conditions to which the wood structural members had been subjected.

The apparent ease with which subterranean termites penetrate the average lime mortar shows the necessity for a different type of mortar below grade, or for coating the exterior surfaces of all brickwork below grade with a coat of rich Portland cement mortar.

Case No. 4. This was a two-and-one-half-story frame residence with siding exterior, built in 1914 at a cost of approximately $12,000. The section of the 6 inch × 8 inch laminated girder in the photograph (fig. 140) shows the damage done as a result of exposing the wood footing block under an intermediate post to contact with the surrounding ground. The location of the post and girder is indicated at *A* in figure 141.

The top of the concrete footing supporting the post was 6 inches below the surrounding ground; thus the 3-inch wood footing block resting on the footing was exposed to earth contact on four sides as well as the top. The intermediate post and girder showed no external evidence of damage at the time of inspection. As the wood footing block was surrounded and partially covered with earth, an examination of it was made by drilling, which disclosed the evidence of damage. The footing block being damaged, the bottom of the 6 inch × 6 inch wood post was drilled and, as damage was found at this point, the top of the post 3 feet above was examined. This was also found to be damaged. The exterior surfaces of the laminated girder showed no signs of damage. However, as damage was found at the top of the post, the girder was drilled directly above the post and the condition shown in figure 140 was found. It was necessary to replace the wood girder for its entire length, although the damage did not extend quite to the southerly end. Six floor joists were found to be damaged when the girder was removed. The damage in the floor joists was not very extensive. The cost of the necessary work of repair was $186.

It is interesting to note that in spite of the amount of damage shown in the girder, there was no failure or indication of settlement in the structure above.

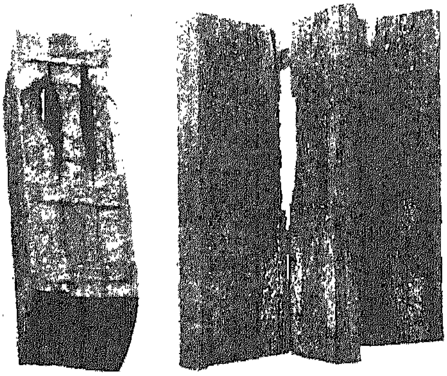

Fig. 140. 6 x 8 inch laminated girder mentioned in subterranean termite damage case No. 4.

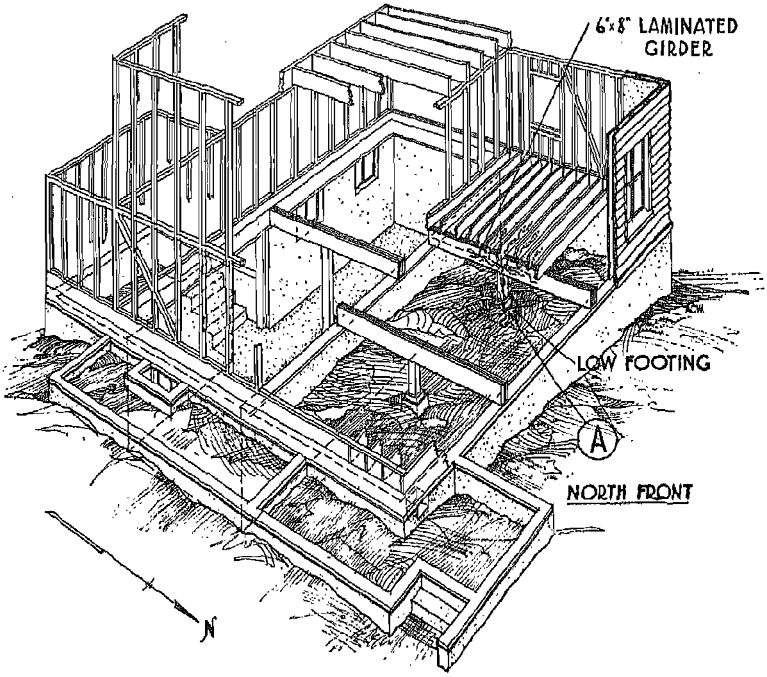

Fig. 141. Sketch of house in case No. 4, showing damage by subterranean termites.

This was undoubtedly due to the manner in which the structure was built, as the framing in evidence below the first floor was far above average.

Case No. 5. The building in question was a two-story frame apartment house about four years old, with stucco exterior. The cost was in excess of $19,000.

The 4 inch × 8 inch girder (*A* in fig. 142) presents an interesting example of the damage which may result where the ends of girders are exposed to an earth fill under concrete porch slabs. This girder was carrying a center bearing partition, an outside wall, and a portion of the concrete porch slab. A survey of this property disclosed the condition of this girder, as well as various other faulty structural conditions. It will be noted on the sketch that certain areas under the building were not accessible for inspection, nor was it possible even to see some of the area. The average clearance under the girders did not exceed 14 inches in the area that was accessible; in the area not accessible the girders in many cases were in contact with the ground. It was necessary to excavate trenches in exceedingly hard ground before a complete inspection was possible. The final inspection disclosed much damage due to subterranean termites and wood decay. The cost of the necessary work of rehabilitation amounted to over $800. All damage found was a direct result of faulty construction.

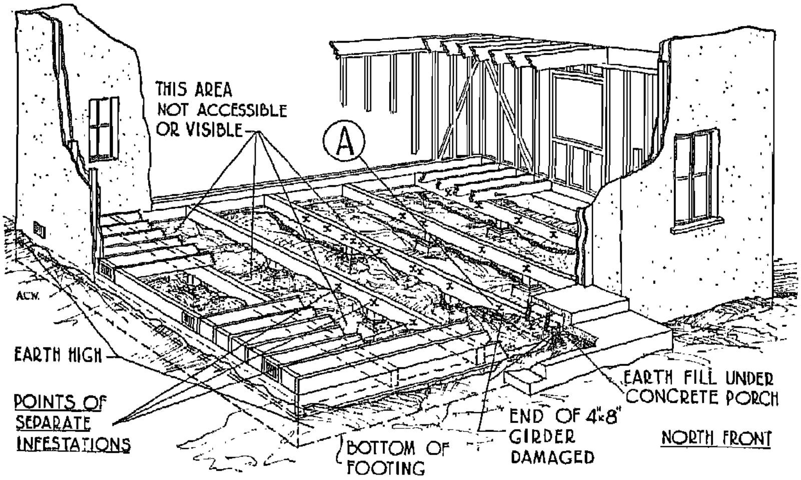
THIS AREA NOT ACCESSIBLE OR VISIBLE
A
ACW.
EARTH HIGH
POINTS OF SEPARATE INFESTATIONS
BOTTOM OF FOOTING
END OF 4"x8" GIRDER DAMAGED
EARTH FILL UNDER CONCRETE PORCH
NORTH FRONT

Fig. 142. Sketch of house in case No. 5, showing damage by subterranean termites.

ANALYSIS OF 500 BUILDINGS INVESTIGATED IN SAN DIEGO COUNTY

The following analysis (Table 51) of 500 buildings was made by a conservation engineer from records obtained during the regular course of his business between 1927 and 1932. Most of the buildings reported on were in the vicinity of San Diego, California. These buildings were not examined solely for the purpose of detecting wood decay or the presence of termites, although

TABLE 51

This information has been compiled by G. Edward Chase, Conservation Engineer of San Diego, California. The 500 cases used in compiling this report were taken at random from over 1,200 field reports in his possession and are the result of actual investigations. This report is furnished the Termite Investigations Committee at its request	Type of building				Totals	Percentages of totals (500 cases)
	Stucco exterior	Wood exterior	Brick or tile veneer	Brick exterior walls		
FOUNDATIONS						
Concrete, properly constructed	180	151	7	3	341	68
Concrete, improperly constructed	45	99	....	....	144	29
Wood	.....	15	....	....	15	3
Total	225	265	7	3	500	100
INTERMEDIATE FOOTINGS						
Concrete, properly placed	85	84	2	....	171	29
Concrete, improperly placed	140	176	5	3	324	56
Wood	70	15	....	....	85	15
Total	295	275	7	3	580	100
FOUNDATION VENTILATION						
Adequate	50	176	2	1	229	46
Inadequate	175	89	5	2	271	54
Total	225	265	7	3	500	100
PORCHES AND STEPS						
Concrete, improperly built	450	243	1	....	694	60
Concrete, properly built	35	14	6	....	55	5
Wood, improperly built	200	168	....	....	368	32
Wood, properly built	20	17	....	....	37	3
Total	705	442	7	....	1154	100
SOIL CONDITIONS						
Dry	80	132	1	1	214	43
Damp	100	83	4	2	189	38
Wet	45	50	2	....	97	19
Total	225	265	7	3	500	100
No débris on ground	5	13	....	1	19	4
Débris on ground	220	252	7	2	481	96
Total	225	265	7	3	500	100
CLEARANCE BELOW FLOOR						
Satisfactory	187	226	7	3	423	85
Unsatisfactory—partial inspection only	25	37	....	....	62	12
Unsatisfactory—no inspection possible	13	2	....	....	15	3
Total	225	265	7	3	500	100
SOIL-NESTING TERMITES						
Found in soil or débris on ground	216	263	7	3	489	98
No evidence of presence found	9	2	....	....	11	2
Total	225	265	7	3	500	100

TABLE 51—*(Concluded)*

This information has been compiled by G. Edward Chase, Conservation Engineer of San Diego, California. The 500 cases used in compiling this report were taken at random from over 1,200 field reports in his possession and are the result of actual investigations. This report is furnished the Termite Investigations Committee at its request	Type of building				Totals	Percentages of totals (500 cases)
	Stucco exterior	Wood exterior	Brick or tile veneer	Brick exterior walls		
SOIL-NESTING TERMITES (*cont'd*)						
In structure—no replacement necessary	65	88	1	1	155	31
In structure—replacement necessary	10	25	6	2	43	9
Corrections recommended to prevent damage	150	152	....	....	302	60
Total	225	265	7	3	500	100
DRY-WOOD TERMITES						
In structure—no structural repair necessary	19	24	4	3	50	10
In structure—structural repairs necessary	1	6	....	....	7	1
No evidence of presence found	205	235	3	....	443	89
Total	225	265	7	3	500	100
WOOD DECAY						
Structural damage found	45	31	....	....	76	15
Corrections recommended to prevent damage	165	222	7	2	396	79
All structural conditions satisfactory	15	12	....	1	28	6
Total	225	265	7	3	500	100
WOOD-BORERS						
Damage slight	10	16	....	....	26	5
Replacement necessary	8	12	1	3	24	5
No evidence of presence found	207	237	6	....	450	90
Total	225	265	7	3	500	100

the presence of one or both was found in nearly all cases. Neither were the buildings entirely representative of all buildings in the geographical area covered, since a majority of the examinations were made as a result of damage already discovered by the owner. Therefore, no conclusions as to the condition of buildings in general with reference to termite damage can properly be drawn from this analysis. It does afford valuable information, however, as to the structural and sanitary conditions in the buildings examined and the relation between such conditions and termite damage.

Table 51 and the explanatory notes were prepared at the request of the Termite Investigations Committee.

EXPLANATORY NOTES

SUMMARY

If all of the 1,200 cases inspected were considered, the percentages as listed might show some variation. However, this report is accurate in so far as the 500 cases in question are concerned.

FOUNDATIONS

Some of the buildings inspected had partial wood foundations; however, these sections were not considered as "wood foundations," but are classified as "improperly constructed" foundations. The wood foundation figures represent structures where wood mudsills, etc., were used in lieu of concrete foundations.

INTERMEDIATE FOOTINGS

It will be noted that the cases of the three classes of footings total 580, and the percentages as figured were made on this basis. The number of cases in this instance are increased, because in many structures both proper and improper concrete footings have been used, or else supplementary footings of wood have been placed in addition to the regular concrete footings required by ordinance. The number of cases of wood footings, however, also includes all cases where wood footings have been used exclusively. Improperly placed concrete footings are footings not having ample clearance above ground, footings from which the wood forms have not been stripped, and footings of insufficient size, or those constructed of inferior material.

FOUNDATION VENTILATION

The legal requirement for foundation ventilation varies in different cities and no attempt was made in this summary to establish any standard amount of foundation ventilation. The cases of "inadequate" ventilation cited represent conditions where additional foundation ventilation was considered necessary for the protection of the property. Cases have been found where the required amount of foundation ventilation was provided in the building but, because of the manner in which it was placed, adequate ventilation has not resulted, due principally to the fact that cross ventilation, which is so necessary, had not been provided. Cases of this nature are few and should not be considered as affecting the percentages shown, for in most of the cases examined additional foundation ventilation was suggested entirely because of a recognized shortage, or to overcome wet soil conditions. These recommendations were based more on conditions requiring additional ventilation than on the amount in place or the amount required by an individual building code.

PORCHES AND STEPS

The number of porches totals 1,154. This is due to the fact that most dwellings examined had two or more porches. Many reports show wood porches and steps, as well as concrete porches and steps in place in the same building. The percentages as figured are based on the number of porches rather than the 500 buildings in question. Improperly built concrete porches are so classed as a result of faulty structural conditions, such as earth under the concrete slab in contact with the wood structural members, wood retaining walls supporting the earth fill, and wood buttress walls or other enclosures where wood is in contact with the earth fill under the concrete slab. If wood porch or step areas are not accessible for inspection, or any of the wood used in the construction thereof is in contact with the ground, they are classified as faulty construction.

SOIL CONDITIONS

Soil conditions shown to be "damp" or "wet" are the result of various causes, the most common of which are faulty soil drainage, excessive irrigation, insufficient foundation ventilation, leaking water or sewer lines, and ice box drains not extended to the outside of the foundation wall. It will be noted the percentage showing débris on the ground is unusually high, and in this regard it should be borne in mind that no attempt has been made to differentiate between a large or small amount of wood or other débris on the ground, as it is conceded that any material of this nature on the ground under a structure constitutes a menace.

CLEARANCE BELOW FLOOR

In preparing this report, proper clearance below the floor has been based on the accessibility for inspection purposes only, and no attempt has been made to establish what may be considered proper clearance, as it has been found that the building codes of various cities are not in accord as to the clearance required. Clearances below floors mentioned as "unsatisfactory" are cases where no inspection of the area below the first floor was possible, because the openings in the foundation were of insufficient size to permit entry; or where the structure was built so close to the ground that proper inspection was not possible; or where inspection of only part of the area was possible.

SOIL-NESTING TERMITES

The relation between evidence of termites in débris or soil under a structure and the cases showing no evidence of termites should not be taken as an indication of the amount of damage by subterranean termites in this district, as is well shown by the low percentage of soil-nesting termites in structures where structural replacement was necessary.

The high percentage of cases requiring corrections to prevent damage does not necessarily imply costly alterations. Under this classification, the lowering of earth to a point of safety around intermediate concrete footings, along the interior or exterior of foundation walls, is considered as necessary recommended change, and does not represent such costly correction as the sealing of concrete porches and the substitution of proper concrete foundations for non-resistant wood. In the cases where the replacement of material was considered necessary, such replacement was not suggested solely because of the presence of subterranean termites. Such recommendations were made only where a sufficient amount of structural damage had been done to impair the safe use of the wood structural members in question. Corrections were recommended, however, where structural conditions had to be changed to prevent infestation by subterranean termites through channels not possible to detect until damage has resulted.

DRY-WOOD TERMITES

Under the heading of "no structural repair necessary" it is not intended to convey the impression that no structural work was necessary, for it is often necessary to remove certain wood members to permit the proper treatment of wall studding, etc. This work is not construed as necessary structural repairs. Under "structural repairs necessary" only those cases are included where it was deemed necessary to replace the infested structural members because they had been damaged structurally. The cases observed where the replacement of lumber was necessary because of structural weakness caused by dry-wood termite infestation have been relatively few.

WOOD DECAY

"Structural damage" represents, in this case, the work of replacing any wood in which dry rot or wood decay is in evidence and where it is conceded that the infested material cannot satisfactorily be treated with any assurance of safety. The steps necessary to prevent future damage by fungi producing wood decay include the correction of all structural conditions from which such damage may result. Structural conditions which will eventually lead to wood decay may exist in a building even though the decay is not in evidence. These conditions consist of improperly constructed earth-filled porches; improperly built wood porches and steps where non-resistant wood is in contact with the soil or where such wood may be damaged by moisture due to insufficient ventilation; wood footing blocks which, although resting on concrete piers, are in contact with the ground; also insufficient foundation ventilation, which may result in damp or wet soil conditions. The corrections recommended are not always of a costly nature, but are made with the intent of preventing future costly repairs by the correction of structural conditions recognized as a direct cause of wood decay damage.

WOOD-BORERS

Under this heading are cited the cases of damage by the powder-post or death watch beetle; no other wood-boring insects have been considered. Replacements of structural members were recommneded only where the structural value of the infested timbers was impaired.

ANALYSIS OF 2,500 CASES INVESTIGATED IN MEMPHIS, TENNESSEE

The following analysis (Table 52) of 2,500 cases of damage to buildings was made by a termite control operator. The information is published exactly as submitted by the operator.

TABLE 52

This analysis of 2,500 termite inspections was made for the National Lumber Manufacturers Association, Washington, D.C., by the Knox Ant Corporation, Memphis, Tennessee, December 8, 1931	Brick apartments	Two-story stucco	Two-story frame	Stucco bungalow	Two-story brick	Frame bungalow	Brick bungalow	Totals	Percentages
FOUNDATION									
Concrete	63	78	65	187	339	144	1223	2090	88
Brick	4	1	68	27	13	181	39	333	13
Brick pillars	0	0	10	1	0	57	0	68	3
VENTILATION									
Good	52	39	57	93	215	175	593	1224	49
Fair	5	18	37	59	85	84	396	684	27
Bad	10	22	49	63	52	123	273	592	24
FUNGI									
Excessive	2	0	3	11	2	19	70	107	4
Medium	2	2	8	3	9	34	49	107	4
Slight	0	1	1	3	2	9	14	30	1
DRY ROT									
Excessive	1	0	9	18	6	28	67	129	5
Medium	4	4	17	14	13	45	71	207	8
Slight	0	0	6	5	4	6	3	24	1
MOISTURE									
Excessive	6	5	11	27	19	61	220	355	13
Medium	3	2	12	17	10	65	159	268	9
Slight	4	5	11	18	20	31	111	200	8
TERMITE INFESTATION									
None	6	7	11	13	27	30	104	198	8
Débris only	10	4	13	14	31	44	208	324	13
No structural weakness	24	25	26	52	121	82	395	725	29
Slight structural weakness	3	2	11	21	35	36	151	259	10
Medium structural weakness	14	12	26	27	49	52	181	362	13
Where repairs were necessary	10	29	56	88	89	137	223	632	25

SUMMARY

VENTILATION GOOD—Cross circulation, adequate openings, at least 8 x 14, with full iron or metal ventilators.

VENTILATION BAD—Foundations built with no openings, or openings too small, or improper kind of ventilators in openings, sometimes with bricks turned on end.

FUNGUS EXCESSIVE—Where fungus has covered a large general area or completely covered the basement structure under one or more rooms.

FUNGUS SLIGHT—Where fungus growth has just started.

DRY ROT EXCESSIVE—Where dry rot has covered a large general area or has seriously damaged foundation structures under one or more rooms. It is always associated with bad ventilation.

DRY ROT MEDIUM—Seventy-five per cent of the classification "dry rot medium" and "dry rot slight" is caused by ice box drains. All ice box drains should be piped so that water will drain outside of house.

MOISTURE EXCESSIVE—Largely caused by bad drainage, either no gutters, or faulty downspouts, or improper construction of foundation wall.

MOISTURE MEDIUM—Leaky water pipes, or ice box drains, or seepage from cesspools, or faulty drainage.

A large percentage of the 107 bungalows showing excessive fungus and the 129 bungalows showing excessive dry rot are located in a section recently taken into the city limits. This section is built up almost entirely of brick bungalows of values ranging from $3,500 to $5,000, a majority having no basements. Poor ventilation, septic tanks, cesspools, and bad drainage are responsible for the fungus and dry rot condition in this locality.

This survey covers 2,500 inspections made by the Knox Ant Corporation, Memphis, Tenn., over a period of two and one-half years in the City of Memphis and represents a cross section of every type and class of house.

A close study of this analysis reveals that adequate ventilation eliminates the dry rot and fungus hazard and, in our opinion, if a house is properly constructed and well ventilated, the use of chemically treated lumber is unnecessary. Our inspections do not show a single aggravated case of dry rot or fungus where there was adequate ventilation.

TABLE 53

Kind of damage	Cost	Number of jobs	Per cent number of jobs	Per cent cost of jobs	Cost of average job
Subterranean termites	$254,690.92	2,901	69.00	58.5	$ 87.79
Dry-wood termites	6,507.06	100	2.40	1.5	65.07
Damp-wood termites	252.00	4	.10	.06	63.00
Subterranean and dry-wood termites	26,237.44	220	5.20	6.03	119.26
Subterranean and damp-wood termites	516.50	10	.24	.12	51,65
Subterranean, dry-wood, and damp-wood termites	122.25	2	.05	.03	61,12
Subterranean termites and fungus	108.305.86	638	15.00	24.93	169,89
Subterranean and dry-wood termites, and fungus	10,716.11	45	1.00	2.50	238.13
Subterranean and damp-wood termites, and fungus	999.44	7	.17	.23	142.77
Subterranean, dry-wood, and damp-wood termites, and fungus	124.16	1	.02	.03	124.16
Subterranean termites and borers	3,943.78	38	.90	.91	103.67
Subterranean and dry-wood termites, and borers	1,500.66	6	1.40	.34	250.11
Subterranean termites, borers, and fungus	3,771.78	26	.60	.87	145.06
Subterranean and dry-wood termites, borers, and fungus	267.87	2	.05	.06	134.44
Subterranean and damp-wood termites, borers, and fungus	228.20	1	.02	.05	228.20
Subterranean, dry-wood, and damp-wood termites, borers, and fungus	300.00	1	.02	.07	300.00
Dry-wood and damp-wood termites	178.00	1	.02	.04	178.00
Dry-wood termites and fungus	1,457.93	16	.40	.33	91.12
Dry-wood termites and borers	262.07	4	.10	.06	65.52
Damp-wood termites and fungus	160.00	3	.07	.05	53.33
Prevention	13,546.04	145	3.40	3.12	93.42
Inspection	124.75	30	.70	.03	4.17
Totals	$434,302.82	4,201			$103.38

In addition to the above figures, termite operators reported voluntarily the following. These are incomplete in that they do not include a large percentage of work done under the respective heads:

Kind of damage	Cost	Number of jobs	Cost of average job
Fungus	$18,754.53	189	$ 99.23
Borers	1,513.62	37	40.90
Fungus and borers	314.73	2	157.37

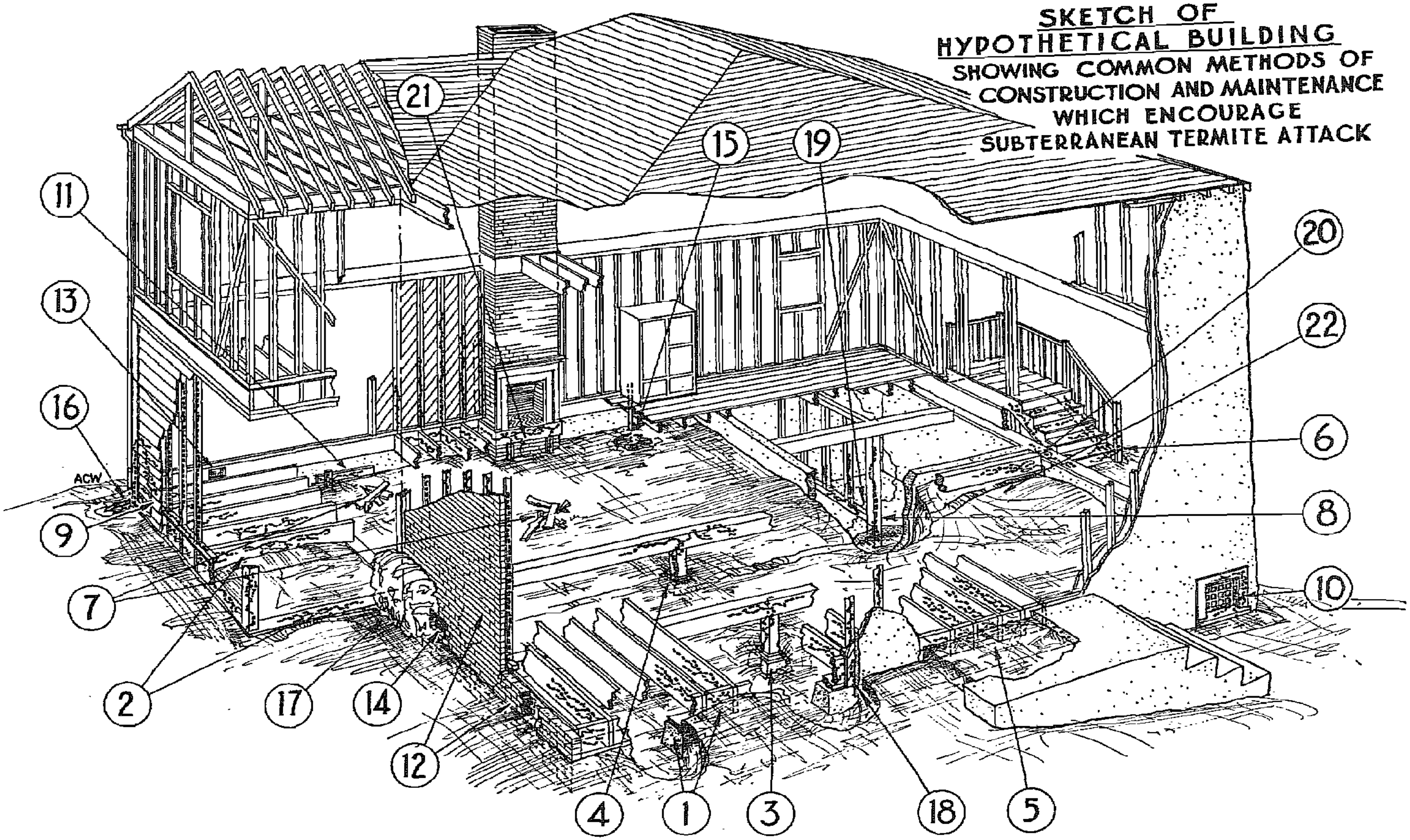

Fig. 143. (For explanation of plate see page 577.)

ECONOMIC LOSS DUE TO TERMITE ATTACK

It was not until 1929 that reports of damage were compiled by governmental agencies. In that year the county agricultural commissioners in the State of California, acting under powers given them by a state law, required reports of all repairs to buildings occasioned by termite damage to be filed with them.

Fig. 143. Types of construction, inviting attack by termites, illustrated in sketch of hypothetical building.

(A) By wood in contact with ground
- *(1)*. Foundation wall too low, permitting wood framing members to come in contact with ground.
- *(2)*. Wood mudsill and wood joists in contact with ground.
- *(3)*. Properly constructed intermediate concrete pier, improperly maintained. Soil has been thrown against one side of pier and is in contact with wood footing block resting thereon.
- *(4)*. Improperly constructed intermediate concrete pier. Top of concrete pier is below surface of ground.
- *(5)*. Wood framing members in contact with earth fill under concrete porch. Concrete foundation wall should have been carried up to top of concrete porch slab.
- *(6)*. Exterior wood porch and steps in contact with ground.
- *(7)*. Fuel wood, scraps left from construction of building, and casual wood of any kind attract termites.
- *(8)*. Post extending through concrete floor to ground below.
- *(9)*. Exterior wood siding in contact with ground.
- *(10)*. Wood frame around foundation vents is in contact with ground.
- *(11)*. Form boards, used in placing concrete, have been left in contact with ground.

(B) By improper construction of foundation
- *(12)*. Solid brick foundation wall and veneer, with lime mortar joints which permit entry of termites through joints. See also *(1)*, *(2)*, *(3)* and *(4)* above.

(C) By improper construction of porch
See *(5)* and *(6)* above.

(D) By improper or inadequate ventilation
- *(13)*. Vent too small for area to be ventilated. Vent is also improperly placed for cross-ventilation.
- *(14)*. Ventilation interrupted by dense shrubbery in front of vent opening. See also *(10)* above.

(E) By improper drainage or excess of moisture
- *(15)*. Improper maintenance of refrigerator drain. Water accumulating under house attracts termites. Drain should be led to outside of building.
- *(16)*. Improper maintenance of roof drain pipes. Water should be led away from building.
- *(17)*. Excessive watering of shubbery or planting areas attracts termites.

(F) By improper construction on the exterior wall
- *(18)*. Stucco not properly bonded to concrete foundation wall permits hidden entry of termites to framework of building. See also *(9)* and *(12)* above.

(G) By scrap wood, form lumber and other débris left beneath the house. See *(7)* and *(11)* above.

(H) By cracks in concrete
- *(19)*. Cracks in concrete floors (or walls) permit entry of termites.

(I) By miscellaneous structural defects
- *(20)*. Wood girder entering foundation wall not placed in wall box and end of girder not treated with preservative.
- *(21)*. Wood placed near chimneys, where heat will attract termites.
- *(22)*. Insufficient clearance between girder and ground below makes inspection difficult and permits easy access to the wood by the earthen towers built up from the ground below by termites.

Table 53 shows the number of jobs, their cost, and kinds of termites involved, in reports submitted to the County Agricultural Commissioner for Los Angeles County during the period September 1, 1929 to August 15, 1931.

In another county in southern California 400 cases of repairs to buildings were reported to the Committee by a termite control operator as being occasioned by subterranean termite damage, dry-wood termite damage, and wood decay. The following tabulation shows the amounts spent for repairs. These amounts do not include sums spent on rehabilitation of structures, such as replastering walls, painting, or other items not directly due to damage by any of the pests listed.

Subterranean termite damage	$34,602.74
Dry-wood termite damage	7,112.72
Wood decay	66,038.47

The above tabulations represent the sum total of information obtained by the Committee on the subject of economic losses occasioned by termite damage to buildings, except for isolated cases. Many estimates of the total damage done by termites in counties, states, or in the United States as a whole, have been printed in papers, magazines and in propaganda put out by advocates of termite control methods or materials. No authoritative information as to how these figures were obtained has been found. The Committee believes that it is difficult to estimate the total damage occasioned by termites in any geographical area. Since no statistical evidence, other than that included herein, is available to the Committee, no estimate of the total loss attributable to termites is offered.

METHODS OF PREVENTING DAMAGE BY SUBTERRANEAN TERMITES

The most important method of preventing damage by subterranean termites is to keep all wood away from contact with the ground. If this is not feasible, use wood impregnated with a sufficient amount of proper chemicals (chap. 34). Analysis made by the Committee of 1,000 cases of damage by subterranean termites (p. 560) has shown that attack in more than 90 per cent of the cases could be traced to contact of wood with the ground.

Specific recommendations follow for preventing termite damage by the application of the above mentioned and other precautions to the parts of buildings and to the building site.

Figure 143 of a hypothetical building shows common faults in construction and maintenance which encourage attack by subterranean termites. The discussion appears in the explanation of the figure.

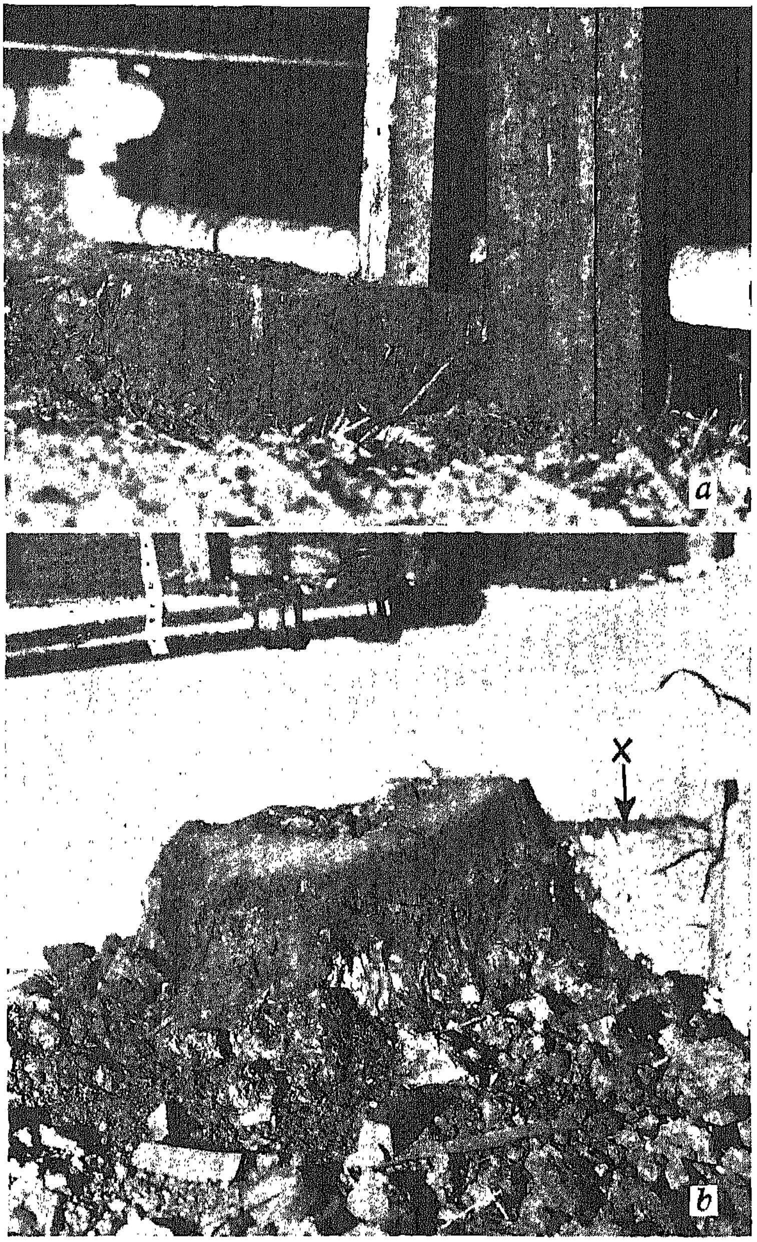

Fig. 144. Some causes of termite attack. *a*. Tree stump left under apartment building. Examination revealed heavy infestation of stump by subterranean termites. A 4-inch × 4-inch post on the stump is a floor support. This provided the termites with a direct path to the joists. Intermediate post beside the stump rests on a concrete pier which has been covered with soil. Steam pipe helped to provide ideal conditions for infestation. *b*. Foundation wall built over tree stump. Part of stump also appears on outside of structure. Subterranean termites infested the stump. *X* indicates termite tubes from stump toward sill.

BUILDING SITE

It is essential that the site of the building be free of plants, stumps, roots, dead weeds, grass, loose wood, and other material containing cellulose (figs. 144, 145, 161). Clear the ground of roots to a depth of 18 inches or more. The application of chemicals to the ground will often aid in destroying existing colonies of termites and in discouraging the migration of new colonies to the site (chap. 40).

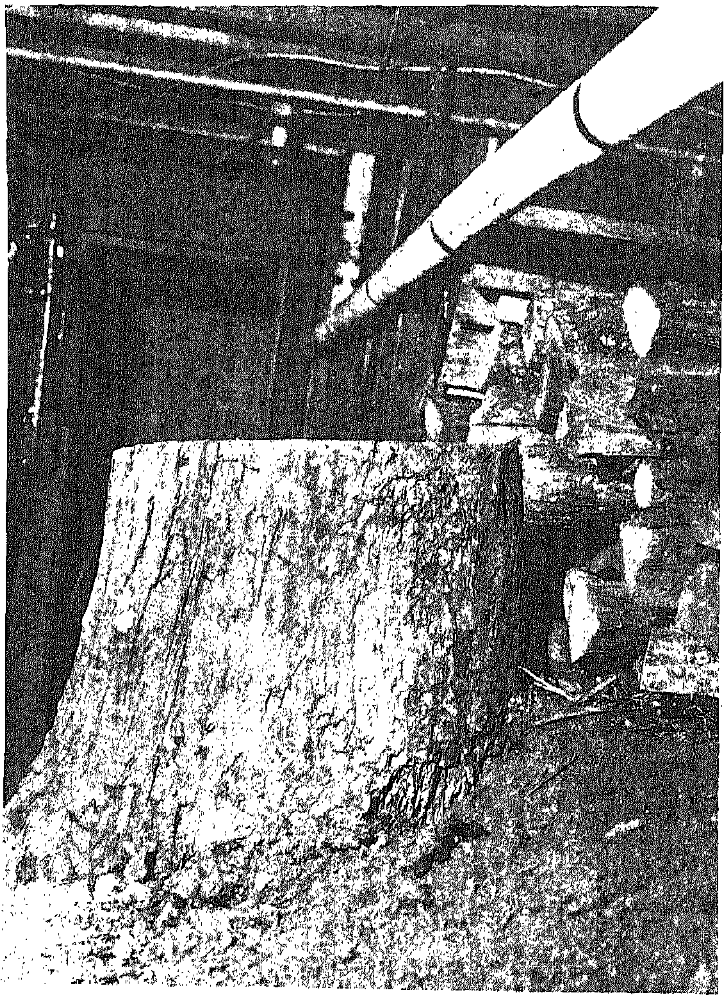

Fig. 145. Another tree stump left under the apartment building, as in figure 144. The stump is infested with subterranean termites. The firewood piled in contact with the ground and the stump may also provide an avenue of attack.

It is desirable to loosen the original soil on the site for a depth of one foot or more beneath the surface when the structure is to be erected without a cellar or basement under its entire area. The purpose of this is to discover roots, stumps, or pieces of wood which may be present in the soil and which if left there may form reservoirs for future termite breeding. Level the ground to avoid mounds under the building.

On an area where another structure formerly stood, be sure that hidden food reservoirs in the form of loose wood or débris are not left. The following suggestion regarding this precaution is from a member of the Committee:

> In the South and parts of the Southwest smaller houses are largely built on piers or post foundations, and the space beneath is left entirely open. In some cities, particularly in Gulf Coast regions and ports, such open area is required by ordinance. Frequently builders do not "skin" the ground to remove the stems and roots of shrubs, weeds, grasses, stumps of small trees, etc., but merely clean off the surface and build piers. Such practice leads to termite infestation. The area to be covered by the structure should be well cleaned of all sources of food supply.

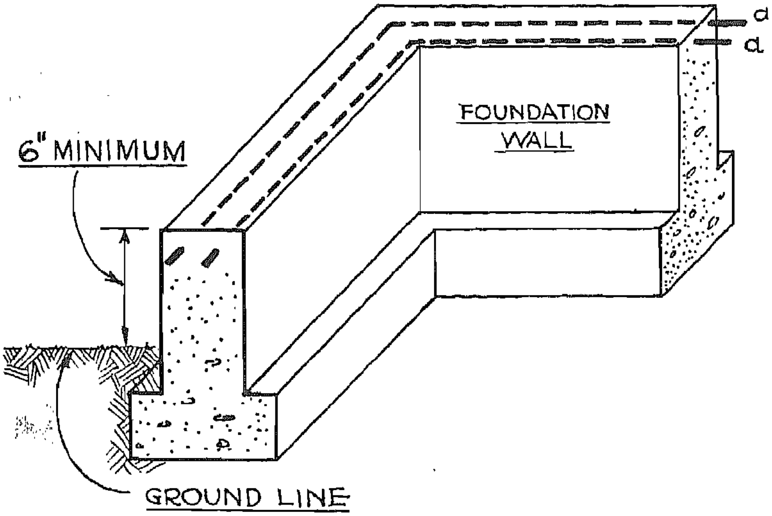

Fig. 146. A recommended type of foundation wall. *a, a.* Steel rods, all splices lapped at least forty times the diameter of the rod. The rods prevent cracks from extending up through the foundation. Such cracks, if allowed to form, are ideal runways from the ground to the bottom of the sill. These rods should be used in both concrete and masonry walls. From *Calif. Agr. Exp. Stn. Circ. 318, fig. 34.*

THE FOUNDATION

Foundations of adequate masonry or wood made toxic to termites by impregnation with a sufficient amount of proper chemicals should be provided. Concrete foundations should be reinforced with dense, well placed concrete. Brick foundations should be laid with Portland cement mortar with well filled joints, and should be capped with at least one inch of dense mortar. Mortar should contain not less than one-third Portland cement.

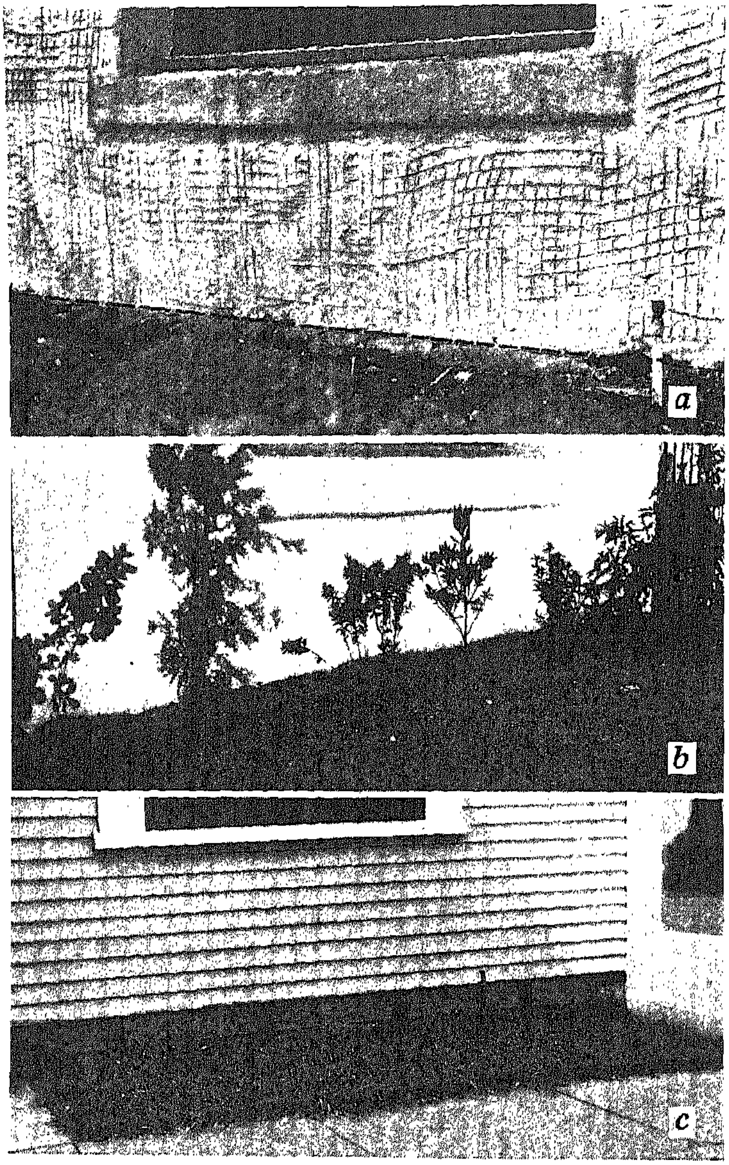

Fig. 147. Conditions at the foundation which invite attack by subterranean termites. *a.* Foundation wall too low. Dotted line is just above the top of the sill which rests on foundation wall. *b.* Same house as in *a.* After top soil had been placed and planting completed the grade level was above sill. *c.* The ends of 2-inch × 12-inch floor joists as shown rest on concrete foundation wall, the top of the wall being 9 inches below the grade level of the soil. The ends of the joists were so badly damaged that they had practically no bearing on the foundation wall.

A 1-inch capping of Portland cement mortar consisting of one part Portland cement, to which may be added 10 per cent, by volume, of hydrated lime, to three parts of sand is recommended for the top of masonry or concrete walls. This is especially valuable in the case of hollow masonry walls and in hollow tile construction. The mortar cap should be adequately reinforced to prevent cracks.

If hollow tile construction is used, one complete course of the tile cores should be filled with properly mixed concrete, or a corrosion-resistant metal plate inserted to entirely seal the hollow cores from the structure above.

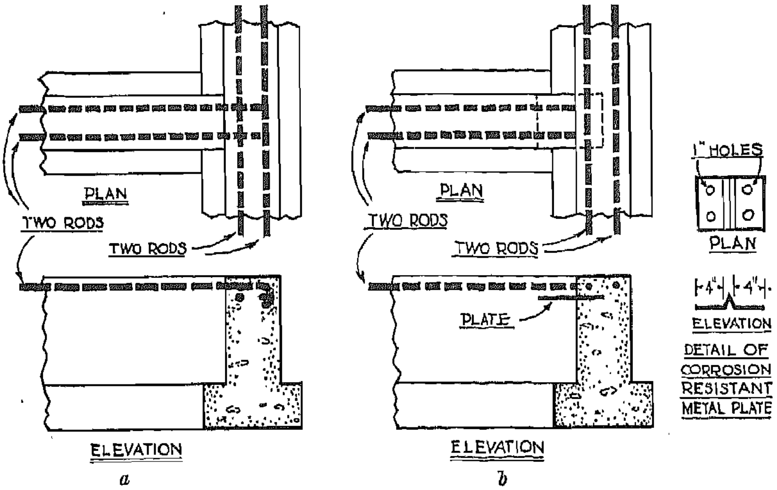

Fig. 148. Construction detail at foundation wall intersection. *a.* Using tie rods. *b.* Using metal plate. From *Calif. Agr. Exp. Stn. Circ. 318, fig. 41.*

Do not skimp in the height of the foundation above ground level (figs. 146, 147). Whether or not a cellar is included in the structure, keep the exterior ground level at least 6 inches below the top of the foundation; increase this distance if possible.

Wherever masonry foundation walls meet or intersect, they should be adequately tied together with steel rods (fig. 146). This will prevent the opening of joints or cracks due to shrinkage of concrete during setting.

VENTILATION

Proper ventilation is primarily for the prevention of decay. It also aids considerably in preventing termite damage. Insufficient ventilation often prevents drying up of moisture. Under suitable conditions moisture will attract termites. It is a fallacious idea that air vents are not necessary when other construction methods are adequate (fig. 149). Good architectural details will always provide for adequate ventilation.

For frame buildings a minimum of 2 square feet of air space is necessary for each 25 lineal feet of foundation wall. Cross ventilation in the direction of the prevailing winds is particularly effective (fig. 150). Be sure that vents are so placed that dead air pockets do not exist.

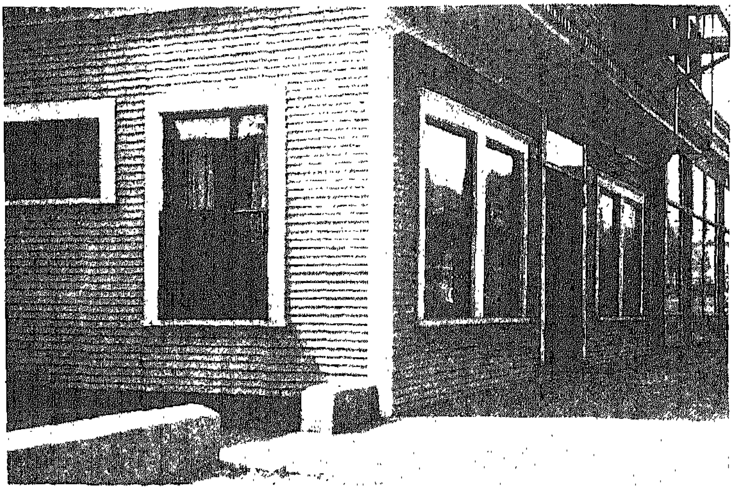

Fig. 149. Construction typical of many store buildings. Note the entire lack of foundation ventilation. This is the same building as that shown in figure 147c. This type of construction invites attack by both termites and fungi.

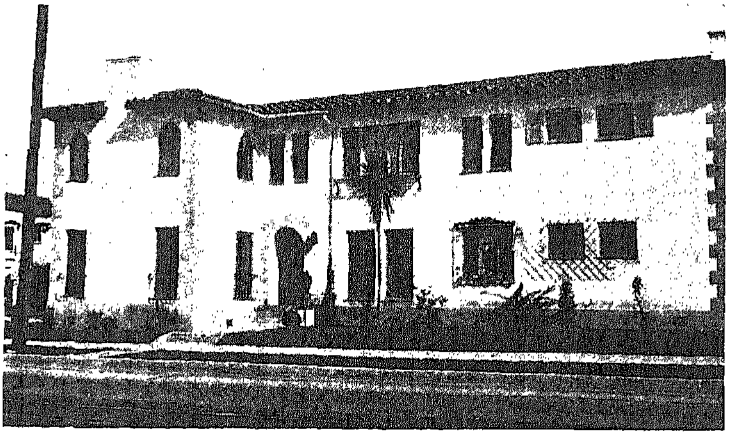

Fig. 150. Air vents in the foundation walls should be well placed and sufficient in number, as illustrated, so as to provide for proper cross-ventilation.

When wood-framed vents are used, see that the frame of the vent is not in contact with the ground (fig. 151).

Vent screens should occasionally be cleared of spider webs and débris, which collect dirt and restrict air currents.

Shrubbery should be so placed and maintained that it will not restrict air circulation through vent openings.

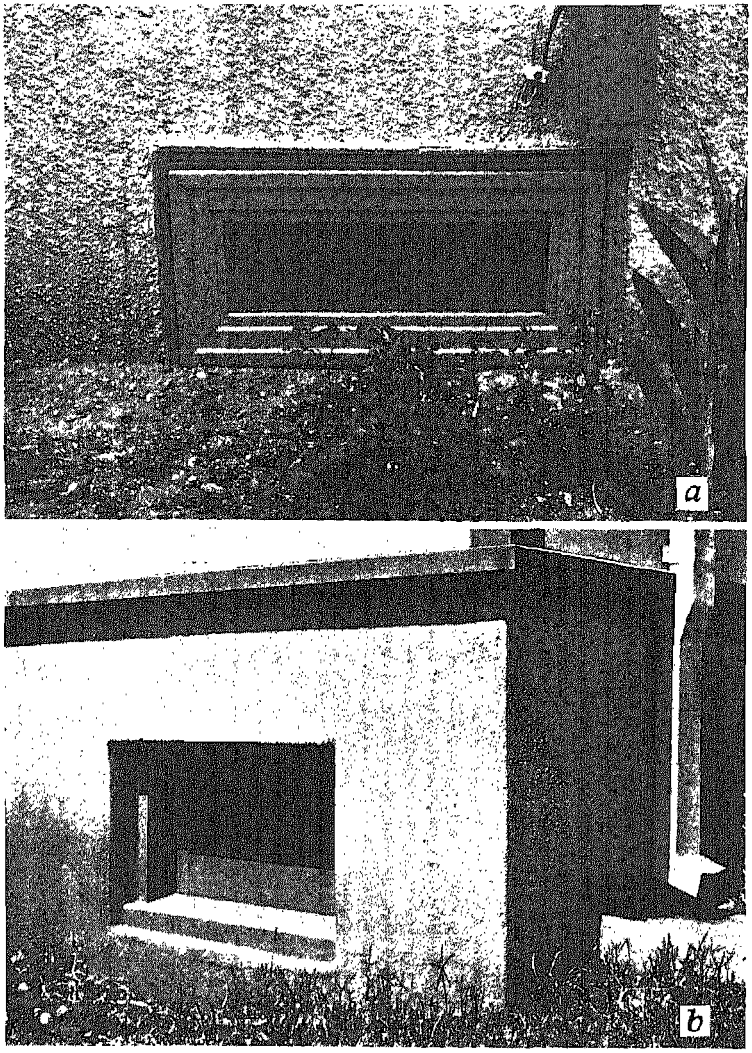

Fig. 151. *a*. Poor air vent construction. Wood frames of vent and screen should not touch the ground. *b*. Good air vent construction. Wood frames of vent and screen do not touch the ground.

GROUND CLEARANCE

Ground clearance should be provided under a structure sufficient to allow a man to move about under the entire building area. Eighteen inches is recommended as a minimum clearance below floor joists; 24 inches is better. Such clearance should be provided whether wood-joisted or concrete slab construction is used, unless the concrete slab rests directly on the ground.

PORCHES

In the design and construction of concrete or brick patios, porches, or steps, care should be taken completely to separate the soil under such areas from all adjacent wood members (fig. 152). The top of the foundation wall of the building should be at least level with, and preferably above, the top surface of the patio, porch, or the highest step (fig. 152). Failure to observe this precaution has been the largest single cause of termite infestation and damage reported to the Committee.

Where planting areas are built within patios or porches, the wall enclosing the patio or porch should completely seal off the soil in the planting area from any portion of the wood framing members of the building.

When concrete porch slabs are used, the use of reinforced concrete is recommended. Where such a slab is built, an opening of suitable size should be left in the main foundation of the building to allow for the removal of all wooden forms under the slab. It is advisable, where possible, to place one or more ventilating openings in the porch walls to provide proper ventilation for the area even under a reinforced concrete slab (figs. 154*b*, 155*b*). Where reinforcing is omitted and the slab rests directly on the ground, all wood should be removed from inside the frame before the slab is cast.

CHASES OR SLOTS

Chases or slots are sometimes left in concrete or masonry foundations to receive the ends of girders. Wherever this is done adjacent to an earth fill under a concrete covered porch or elsewhere, care must be exercised that the concrete around this opening is dense and that the sides, top, and ends of the timbers are not in contact with the concrete. It is recommended that those portions of timbers which rest on concrete be coated with hot coal-tar creosote or placed in metal wall boxes. In no case should the timbers extend through the concrete foundation.

CONCRETE FORMWORK

When wood forms and wood spacer blocks for the concrete foundation have served their purpose they should be removed. Do not leave any forms within 18 inches of the ground. Forms left in the ground around foundation walls, footings, and bases of chimneys, often are the direct path whereby termites enter a structure. They may form breeding grounds from which the termites can build runways to the wood above (fig. 157*c*).

METAL SHIELDS

Metal shields may be used between wood and the ground so as completely to prevent termite travel from the ground to the wood above. Although the Committee has no direct evidence of the value of termite shields, other investigators have reported favorably on their effectiveness in tropical countries. If they are used they should be placed over foundation walls and piers, along heater and plumbing pipes, and on all possible locations for runways connecting the ground to wood above.

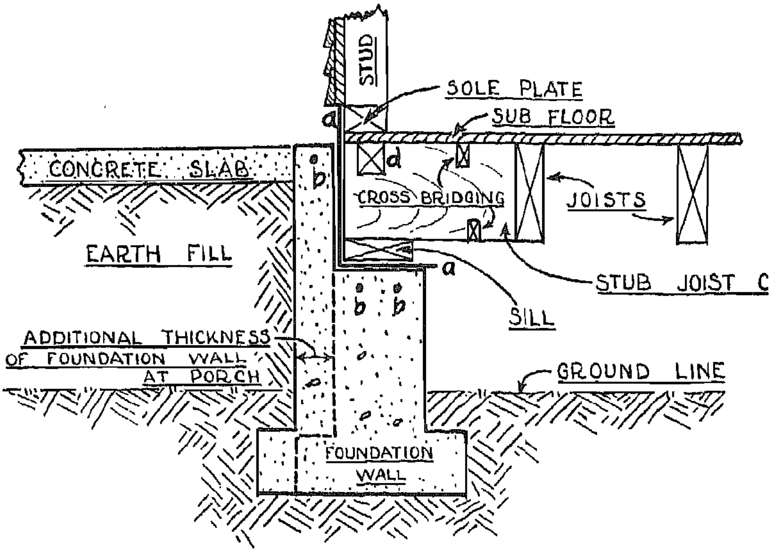

Fig. 152. This detail is recommended where concrete porches or steps are built over an earth fill. The use of cross-bridging is recommended instead of the usual solid headers between joists, in order that all surfaces may be ventilated and inspection made easier. *a.* Corrosion-resistant metal plate extending in front of and under joists and sills. *b.* Reinforcing rods. *c.* Short joists set 16 inches on center extending from wall to nearest joist. *d.* 2-inch × 3-inch braces fitted between short joists.

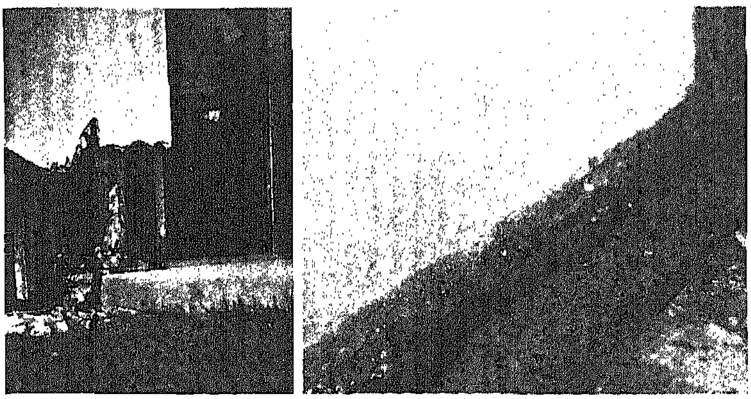
a *b*

Fig. 153. Improper porch conditions. *a.* Foundation wall is below the top of the concrete porch slab. This improper practice has resulted in termite and fungus damage. Foundation wall of house is level with exterior grade of soil. The concrete porch slab on an earth fill is 4 inches thick, which leaves 5 inches of earth fill under the slab in contact with wood members in the substructure of the house. *b.* A planting area between the concrete porch slab and the wall of the house, the soil extending several inches above the top of the concrete foundation. This condition has resulted in termite damage in the sill, ends of joists, and studs. The foundation wall should extend at least 6 inches above the grade level of the top soil.

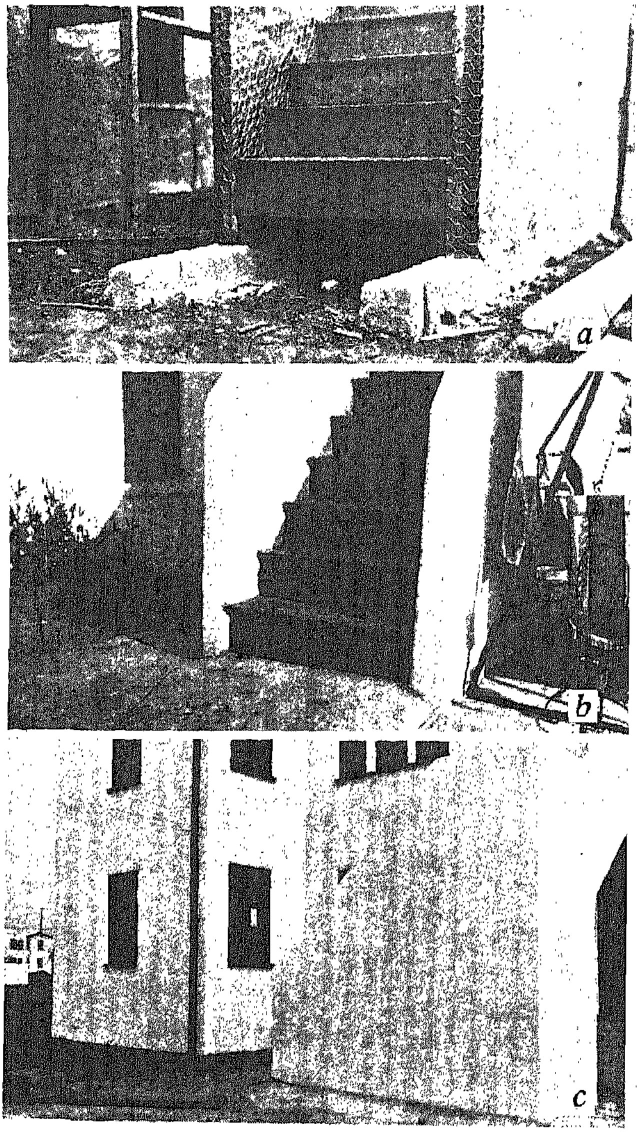

Fig. 154. Improper construction of steps. *a*. Before, and *b*, after completion. The underside of the concrete walk is above the concrete of the foundation of the steps, permitting soil under the concrete walk to be in contact with the wood members of the steps. *c*. Another view of steps illustrated in *a* and *b*. All walls have wood members in contact with soil. Walls and under side of steps are plastered and no air vents have been provided. Proper inspection cannot be made and undetected damage is possible.

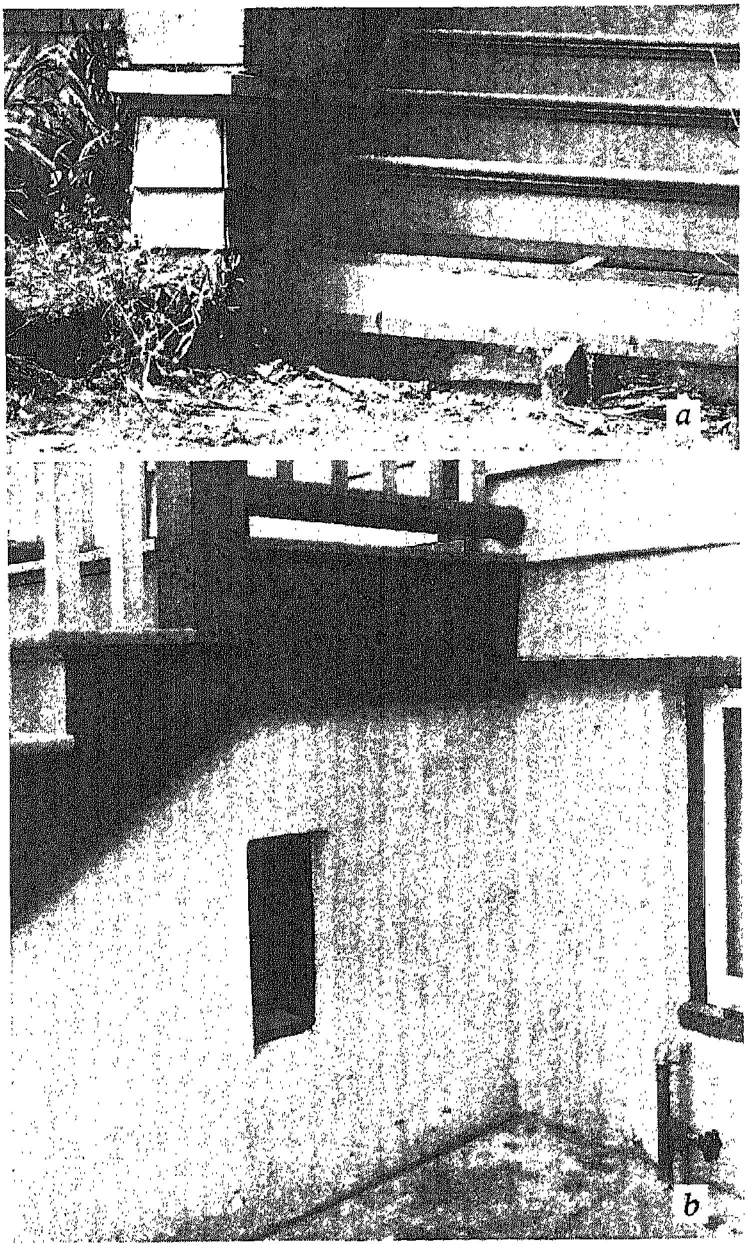

Fig. 155. *a.* Improperly built steps affording termites an entrance into the structure. *b.* Well built steps with proper ventilation of concrete step foundation. A similar vent is on the other side of the foundation.

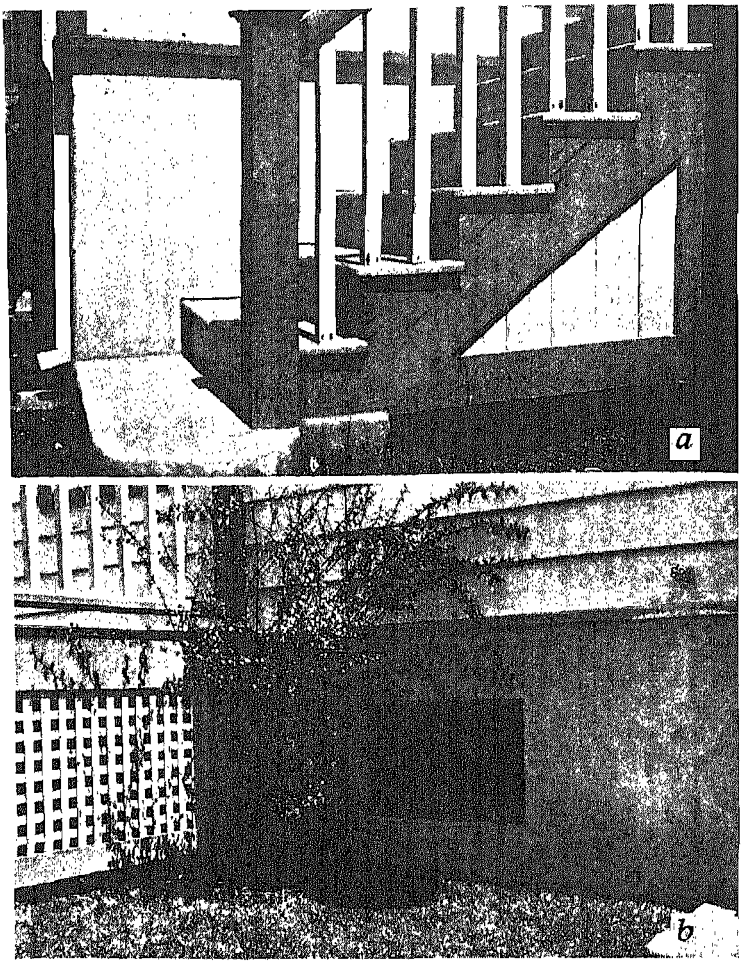

Fig. 156. *a.* Well built wood steps. Note that the steps are not in contact with the soil. *b.* Well built porch. Note that lattice work is not in contact with the soil. Ends of lattice work rest on concrete piers, which act as supports for corner posts.

PIPES

Conduit, heating, and plumbing pipes should be arranged so as to prevent termites from gaining access to the structure above, which they sometimes do by building their earth-like runways along the outside of the pipe. Pipes passing through concrete should fit tightly so that no openings, however minute, are left in the concrete around the pipes. Pipes passing through floors from the ground should have metal shields around them between the floor and the ground.

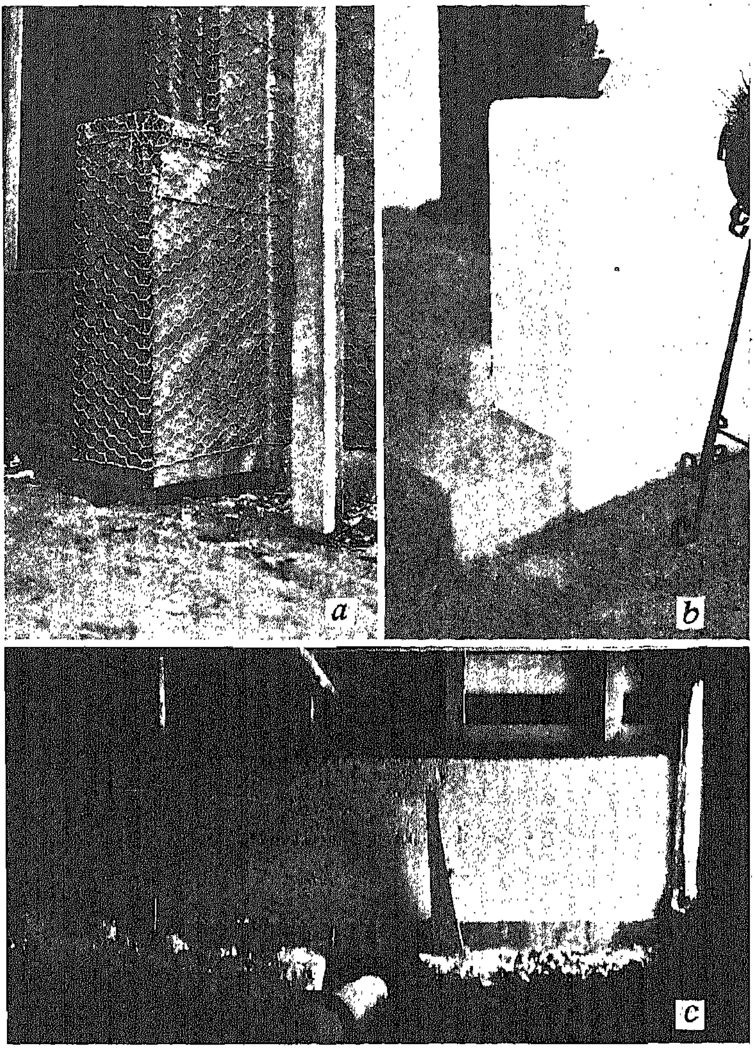

Fig. 157. Improper construction of buttress wall and wall of house back of concrete steps. *a*. Before, and *b*, after completion. Note wood members of buttress wall in contact with soil and without proper foundation. Because of the inadequate height of the concrete foundation wall back of the concrete steps, the earth fill supporting the steps is held in place by wood members under the door and in the buttress wall, affording no protection against termites or decay. *c*. Form board left in place along interior side of foundation wall. Form boards should be removed because they often afford breeding places for subterranean termites.

CONCRETE FLOORS

Concrete floors laid on the ground should be constructed so as to prevent the formation of joints or cracks which might provide concealed points of entry to any wood above.

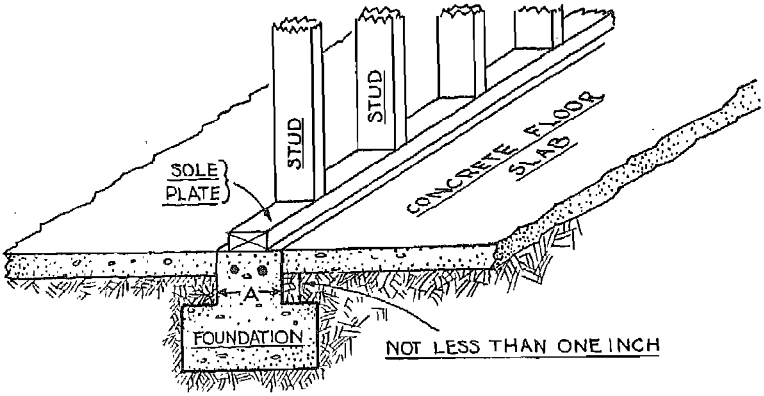

Fig. 158. Detail recommended for concrete floor at bearing partition. The dimension *A* should be great enough so that the joint between the floor slab and the foundation is not covered by the sole plate. The bottom of the sole plate should never be below the top of the finish floor.

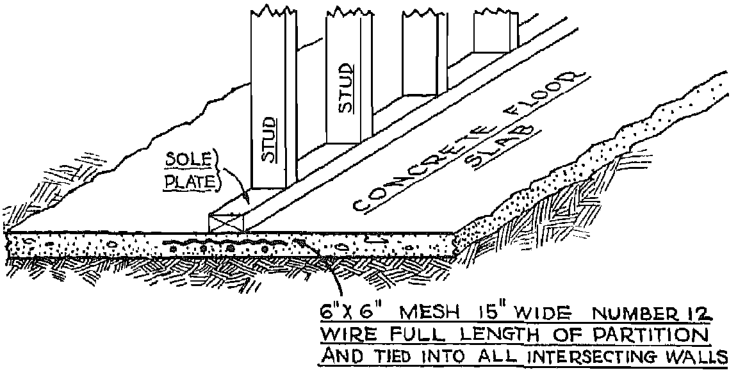
STUD
STUD
SOLE PLATE
CONCRETE FLOOR SLAB
6"X 6" MESH 15" WIDE NUMBER 12 WIRE FULL LENGTH OF PARTITION AND TIED INTO ALL INTERSECTING WALLS

Fig. 159. Detail recommended for concrete floor at non-bearing partition. Sketch shows a case where location of partition is known in advance of construction. When the location of the partition is not known before slab is laid, the entire slab should be reinforced and tied to surrounding walls. From *Calif. Agr. Exp. Stn. Circ. 318, fig. 40.*

WOOD POSTS ON CONCRETE

Where wood posts rest on concrete, as illustrated in figures 143 and 160, the bottom of the posts should never be below the finish surface of the floor. Each post should bear on a corrosion-resistant metal plate at least as large as the bottom of the post, with a tight-fitting metal dowel through it.

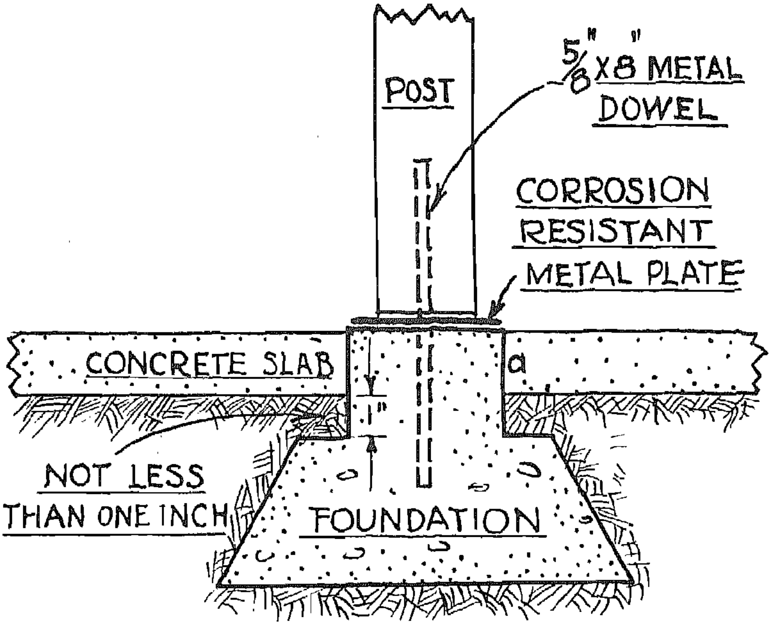

Fig. 160. Wood-post foundation detail. Use vertical sides *a* here, so that floor slab will not crack at juncture with foundation in case of settlement. Do not bring concrete slab down to shoulder of foundation. From *Calif. Agr. Exp. Stn. Circ. 318, fig. 38.*

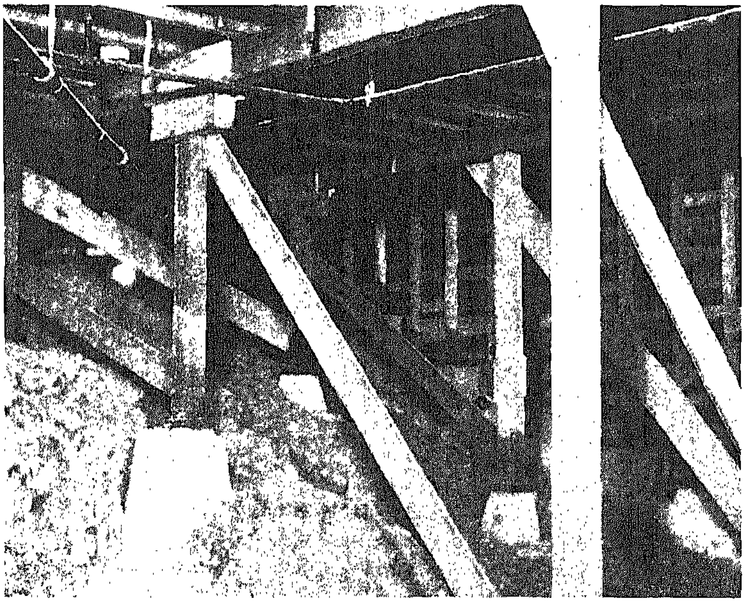

Fig. 161. Intermediate piers should be free of contact with soil for several inches from their tops, as illustrated. When a building is erected on a slope the foundation should be stepped and extended several inches above the soil, as illustrated.

Where wood posts rest on concrete piers there should be a distance of at least 6 inches from ground level to the top of the pier (figs. 143, 144, 161). See that soil is not thrown against the pier. The concrete should be dense and well tamped.

EXTERIOR WALLS

Exterior walls of wood frame buildings should be finished so as not to provide a passageway for termites from the ground into the structure. Wood siding should not extend closer than 6 inches to ground level. Frequent inspection should be made to see that this distance is maintained.

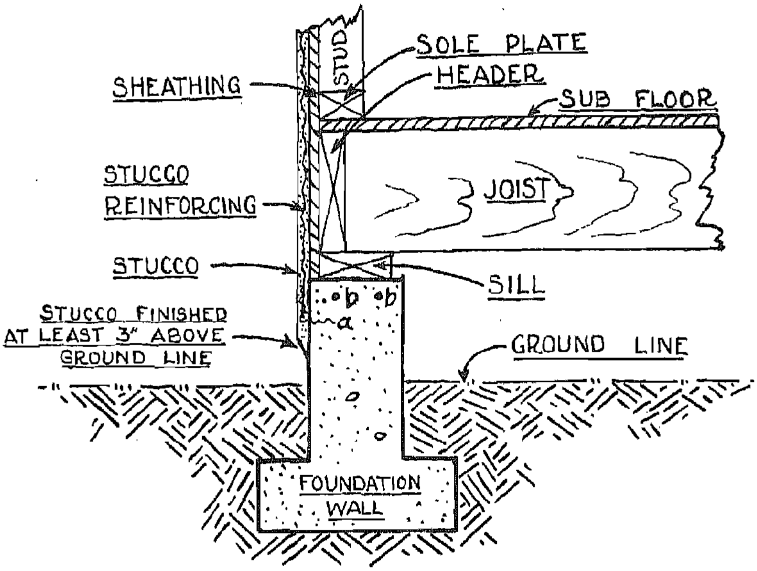

Fig. 162. Recommended method of bonding stucco to foundation wall. Termites frequently enter wood sills and wood joists through cracks formed between the stucco and the concrete foundation wall. To prevent formation of such cracks the stucco should be anchored to the foundation wall as shown. *a.* Galvanized No. 14 wires not over 6 inches on centers (or continuous wire mesh) placed in forms before foundation wall is poured. When stucco reinforcing is applied to outer wall it should be tied to these wires. *b, b.* Reinforcing rods to prevent cracking of wall.

Stucco on an exterior wall, if finished to ground level, should be adequately bonded to the foundation wall. This is necessary to prevent the possible formation of concealed runways by means of which the subterranean termite finds easy access from the ground into the structure above. Before applying stucco to the foundation wall see that the outside of the wall is free from soil and that it presents a clean, rough surface. It is not advisable to finish stucco below ground level. Damp-proofing of the stucco will assist in keeping moisture away from the wood inside.

A recommended method of securing anchorage of stucco to foundation walls is shown in figure 162.

MAINTENANCE

Proper care of a structure after its erection is essential in order to minimize termite damage. Depreciation of a structure due to lack of maintenance is often responsible for repairs which might easily have been avoided. Many buildings, originally well constructed, which would not be subject to termite attack if conditions remained the same as they were at the time of completion of the building, have been found to be damaged by both termites and wood decay because of a lack of proper maintenance. Items which should be given special attention in this connection are the interruption of proper foundation ventilation, the raising of exterior grade levels above the foundation line, the improper storage (under the building) of materials susceptible to termite infestation, leaks in pipes, disposal of water from refrigerator drains, and the presence of faulty soil drainage due to excessive irrigation.

Periodic inspection of the structure and adjacent premises at six-month intervals is recommended as a first essential to proper maintenance. Faulty conditions, if found, should be corrected as recommended.

One of the most important requisites for maintenance is to know the types of termites concerned. Figure 164 shows groups of each of the three common types of termites in natural size. For a discussion of the biology and economic potentialities of the three types see chapters 12–24.

GENERAL CLEAN-UP AFTER ERECTION OF STRUCTURE

When the building is completed, débris under and around the foundation should be removed. Often it is necessary to rake the ground in order to clean it properly. No shavings, paper, or loose or casual wood should be left (fig. 163). Level the ground under the structure. Hummocks of dirt often prevent

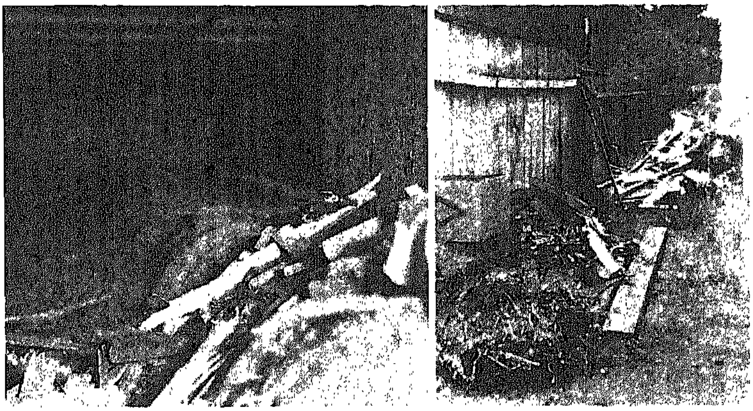
a *b*

Fig. 163. *a*. Débris left under a building often affords a breeding place for termite colonies. *b*. Part of termite-infested débris removed from the ground under an apartment building badly damaged by termites. If proper maintenance had been practiced this material would not have been permitted to accumulate.

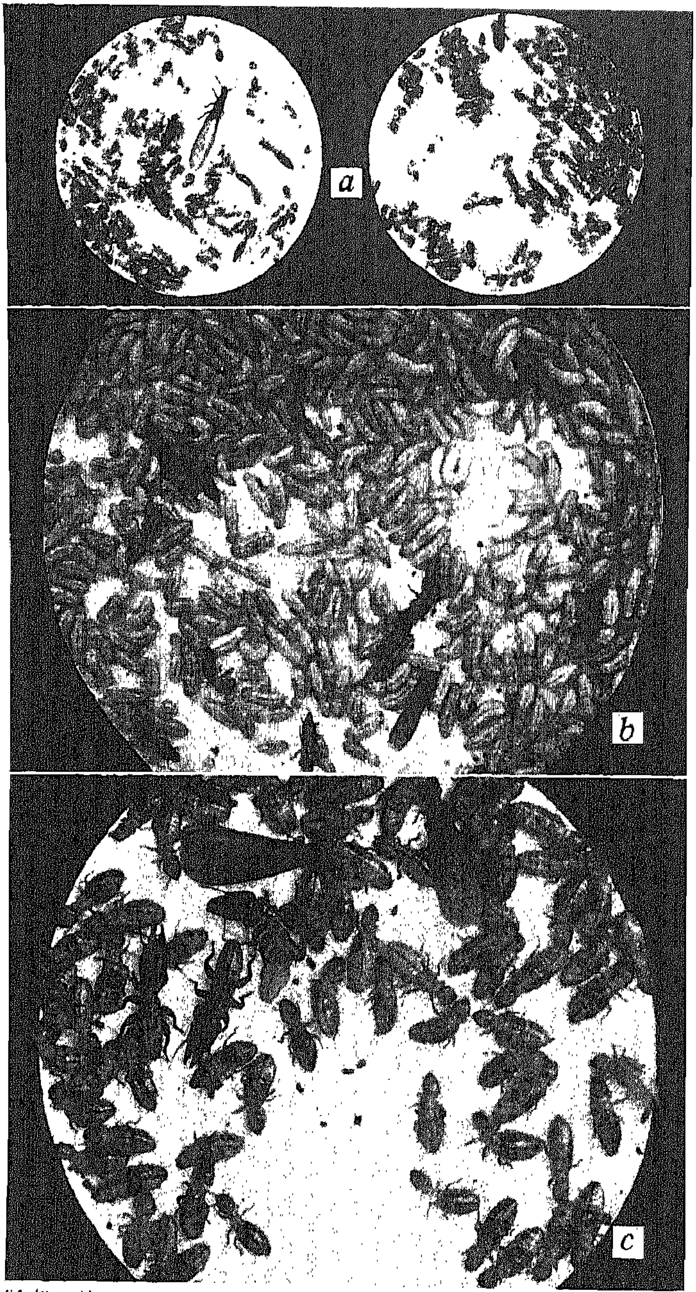

Fig. 164. The three common types of termites, natural size. Each group contains the types commonly encountered in opening a colony, namely, soldiers, winged reproductives, and immature stages known as nymphs. In the case of the subterranean termites, *a*, an additional type, the workers, are present. *a*. The western subterranean termite, *Reticulitermes hesperus*. *b*. The common dry-wood termite, *Kalotermes minor*. *c*. The common damp-wood termite, *Zootermopsis angusticollis*.

complete inspections of the ground area later, or reduce the clearance of wood members. Do not permit the builder to throw waste wood or paper or other débris in any earth-filled area. This has been done many times. In cleaning up be sure that soil does not rest against foundation walls and piers above the points recommended. See that the finish ground level around the exterior walls is at least 6 inches below the top of the foundation wall. Many cases of damage have been the result of carelessness in placing top soil above the top of foundation walls.

METHODS OF PREVENTING DAMAGE BY DRY-WOOD TERMITES

In a region where dry-wood termites are known to be prevalent it is recommended that possible sources of infestation be examined. Inspect nearby tree stumps, dead portions of living trees, poles and posts in the vicinity. If infestation is found, destroy the termites with poison dusts (chap. 38) or burn the stumps. Remove dead limbs from trees. If stumps are found on the site of the proposed building they should be removed whether or not they are infested.

BUILDING STRUCTURE

In a region where dry-wood termites are prevalent it is recommended that material for the structure be kept under a tarpaulin or shed-like covering, particularly during the swarming season (September to December in California).

Use seasoned lumber for construction purposes (chaps. 21, 34, 43).

Use the more durable species of wood, or wood made toxic to termites by impregnation with chemicals, in localities where dry-wood termites are known to be especially troublesome, and when the protection desired will justify the additional cost of such wood.

METHODS OF REPAIRING DAMAGE DONE BY SUBTERRANEAN TERMITES

Examine infested parts. All structurally unsafe materials should be replaced. All removed materials which contain live termites should be burned. All débris and casual wood under the structure should be removed. Where structural faults are discovered, they should be corrected as recommended.

If termite tubes are found on any structures, they should be traced to the ground and search made for buried wood. If this is found, it should be removed and burned. If termites are invading dwellings from unprotected earth beneath the structures, this earth should be sealed with a dense coat of cement not less than 1½ inches in thickness, and all cracks subsequently occurring in it should be filled with creosote and then sealed with asphalt (chaps. 46, 56).

While it is possible, in *dry locations* in buildings, to kill subterranean and damp-wood termites with poison dusts, results of tests conducted by the Committee show this treatment in most cases to be unsatisfactory. Poison dusts must be dry to be effective. Paris green and arsenical smelter dust, not recom-

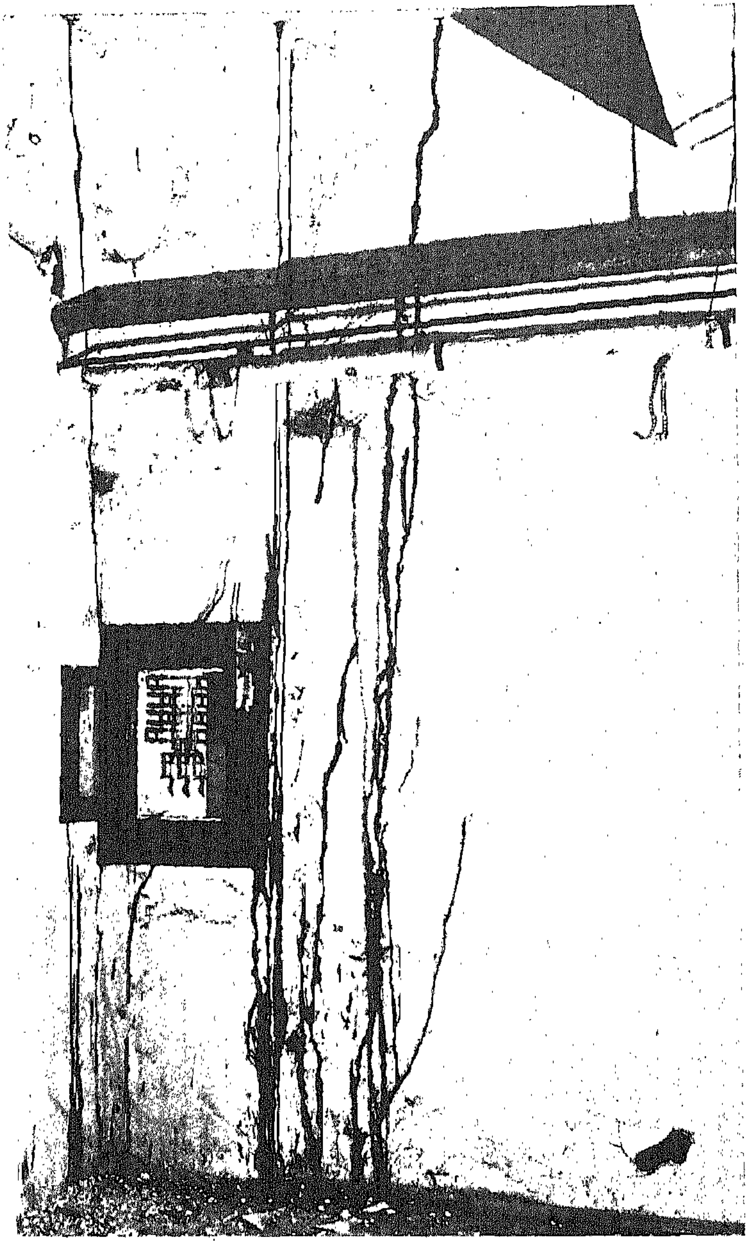

Fig. 165. Exploratory tubes constructed by subterranean termites from the soil under concrete slab to upper part of building, connecting with the food supply of wood. The subterranean termite must maintain a ground connection in order to obtain adequate moisture.

mended for use in and under dwellings, do not cake so easily as does sodium fluosilicate. It must be remembered that the termite colony must be reached by the uncaked dust in order to exterminate the colony and to prevent recurrence of attack. The use of poison dusts for subterranean and damp-wood termites should be considered a temporary measure because of this tendency of the dusts to cake. An inspection soon after treatment should be made.

Look for and remove form boards and spacer blocks left in, or close to the ground around foundations, chimney bases, and piers.

Recommendations as they apply to the component parts of buildings follow.

FOUNDATION WALLS

If foundation walls are cracked and it is thought that termites are entering through these cracks, the walls should be repaired as shown in figure 166.

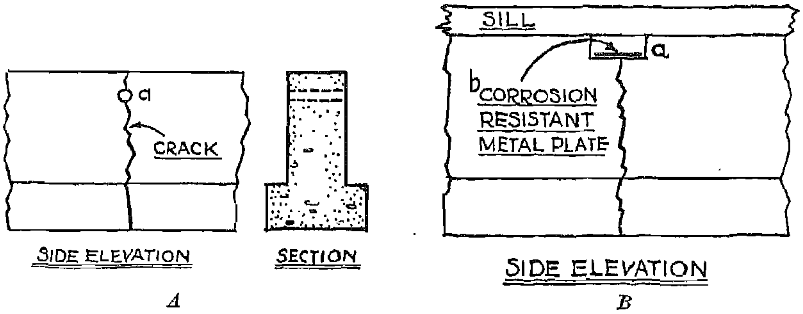

Fig. 166. *A*. Method of repairing cracked foundation wall. Drill a hole, *a*, through the wall following the crack, clean out the hole and thoroughly wet the masonry. Then fill the hole with a rich dense Portland cement mortar. Use only sufficient water in this mortar to make very fragile balls when compressed in the hand. Put a little mortar in the hole and ram it solid with a hammer and iron rod, repeating the process until the hole is completely filled. *B*. Another method of repairing cracked foundation wall. Cut a hole *a*, through the wall. *Place a piece of corrosion-resistant metal, b, the full width of the* wall, lapping about 2 inches on each side of the crack in the bottom of the hole, and fill the hole as directed under *A*. From *Calif. Agr. Exp. Stn. Circ. 318, figs. 42, 43.*

REFINISHING EXTERIOR WALLS

If it is desired to use stucco over an original exterior wall surface of shingles, shakes, or wood siding, it is recommended that the original exterior wall covering be removed between the ground and the top of the foundation wall.

Do not use furring strips on the foundation wall. The exterior of the foundation wall should be clean and clear of soil, paint, and other loose particles to insure a good bond. It is necessary to secure a mechanical bond between the stucco and the foundation wall in order properly to seal this space against undetected termite passage. Damp-proofing of the stucco will assist in keeping moisture away from the wood inside.

VENTILATION

If, upon examination, it is learned that improper ventilation exists in the substructure, adequate ventilation should be provided, as recommended.

CONCRETE FLOORS

If termites are entering through a crack in a concrete floor resting on the ground, the crack should be sealed. Special attention should be given to the condition of the floor under wood posts or partitions. Where cracks exist in the floor they should be repaired as shown in figure 167.

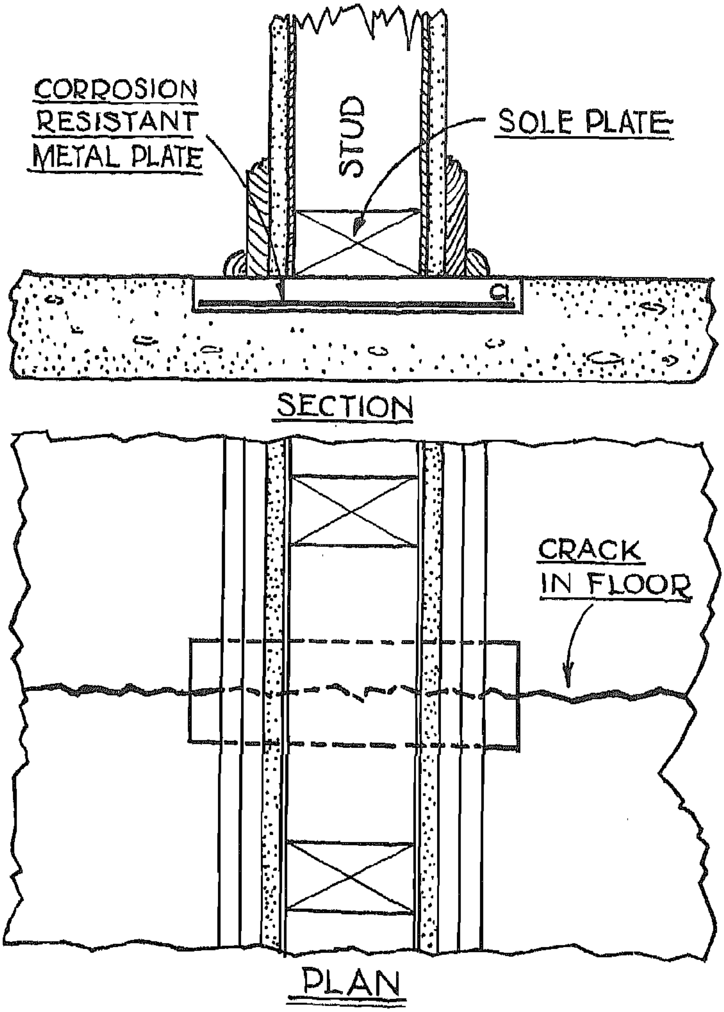

Fig. 167. Method of repairing cracked concrete floor at a partition. Cut a hole *a*, about 4 inches wide and 2 or 3 inches deep in the floor under the partition, as shown, being careful not to crack or shatter the concrete in the bottom or sides of the hole. Clean out *the hole, and* thoroughly wet the concrete. Then place a sheet of corrosion-resistant metal which entirely covers the bottom of the hole, and fill the hole as called for in figure 166*B*. From *Calif. Agr. Exp. Stn. Circ. 318, fig. 44.*

PORCHES, STEPS, AND PLATFORMS

Figure 168*a* shows a common, but improper, method of construction where concrete porches, steps, and platforms are placed against buildings. Recommended methods of repair are shown in figure 168*b*.

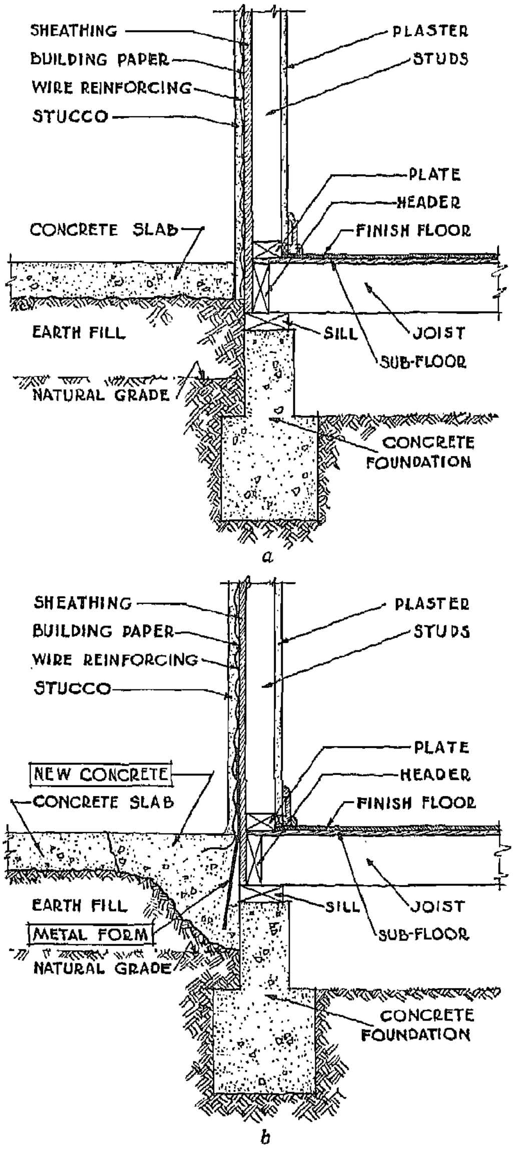

Fig. 168. *a*. Original construction. Earth fill, under concrete porch slab, is in contact with wood sheathing and wood sill. *b*. Recommended repairs. A strip of stucco and a

(Concluded on page 602)

METHODS OF REPAIRING DAMAGE DONE BY DRY-WOOD TERMITES

Inspect possible nearby sources of infestation. If nearby infestation is found, destroy the termites as recommended.

BUILDING STRUCTURE

The presence of recently entered pairs of dry-wood termites in a structure can be discovered by the characteristic frass (sawdust-like material) which they usually leave at the point where a recent infestation has been made (fig. 72 *f-g*). Remove the wax-like plug in the opening at the point of infestation and inject a poison dust or liquid into the hole (chap. 38). It is rarely necessary to remove the infested part unless the affected member is structurally unsound. Attic areas, the interior of the superstructure of the building, and the exterior of the building should be examined for cracks, crevices, and checks in stucco siding around openings and roof rafters. Such cracks should be filled with suitable materials in order to eliminate points of entrance for termites.

INSPECTION

Several weeks after the infested parts have been treated, examine them to see if there is any further termite activity. A second treatment may be necessary. Be sure that all colonies are reached. Examine the structure every six months (chaps. 21, 47) for dry-wood termites if they are known to be present in the locality.

SCREENS

Screens of bronze mosquito netting should be placed over all exterior wall vents. Louvres, louvre-windows, and openings in foundation walls and attics should be sealed this way. The purpose of such screens is to prevent the entrance of swarming termites. For all openings other than those in foundation walls the mesh of the screens must be very fine in order to do any good.

CRACKS

Crevices, checks, and other minute openings in exterior walls should be painted and maintained so as to protect the structure from swarming dry-wood termites.

(*Fig. 168. b.—Continued*)
portion of the original concrete slab have been removed. The earth fill has been excavated wherever it is in contact with the wood. A metal form is fastened to the wall of the building and bent away from the sheathing and sill to prevent new concrete from coming into contact with it. New concrete is then placed as shown.

Chapter 49

POWER, TELEPHONE, AND TELEGRAPH LINES

BY

R. C. BARTON, HAROLD MICHENER, AND W. H. HAMPTON

Specific Recommendations for Prevention and Repair of Termite Damage in Power, Telephone, and Telegraph Lines

For many years industries engaged in the production, marketing, and utilization of pole timber and wooden crossarms have been concerned with a group of destructive agencies which affect the durability of pole line structures. Fungi and various insects, including the termite, are in this group. The study of this problem has resulted in the rather general adoption of practices in the selection and utilization of those materials which are believed to produce the best results, all pertinent factors considered.

Some of the factors affecting the use of pole line timber are peculiar to the individual user, while others are common to all, so the results of any investigation of pole line performance must be regarded with respect to their representativeness for the purpose in hand. Where termite activity is concerned, any investigation in the common interest comes sooner or later to the question, "What is the rate of decay of untreated pole timber and what is the period of effectiveness of any treatment that may be applied?"

The word decay is broadly defined to mean the change from the sound or perfect condition to an inferior state, and so may result from a number of causes, but it is frequently used to mean the breaking down of the substance of which wood is composed by the action of those organisms called fungi. It will be convenient herein, unless otherwise stated, to consider decay to include any condition which might be retarded or prevented from developing by the use of preservatives. The work of both fungi and termites, it will be found, comes within this limitation.

The use of non-decaying materials such as metal and concrete is not considered here, since under many conditions they are unsuitable, and there is necessarily a large volume of pole and crossarm timber utilized each year. It is with this that we are here concerned.

ECONOMICAL SELECTION AND USE OF POLE LINE TIMBER

Preparatory to presentation of the historical sketch which follows, some consideration should be given to the economic problem involved in the selection and use of pole line timber. This has a direct bearing on the conclusions reached and practices established by the utilities as a result of their investigations.

Practically all the pole line material produced in the country is consumed by those public utilities operating the steam railroads, the telephone and telegraph systems, and the light, power, and electric railway systems. The oil companies also make some use of these materials.

The demand for poles varies as between the several utilities according to their respective development and replacement programs, as will be seen from Table 54, compiled from government publications (Bibliog. 92 and 93), which shows for the United States the number of poles purchased by classes of users in specified years. Cycles of general business prosperity and depression also affect expansion and replacement programs, which in turn are reflected in the service life obtained for pole line materials during these periods. Regard must therefore be had for these factors in using the performance records for any period.

TABLE 54

NUMBER OF POLES PURCHASED IN U. S., BY CLASSES OF USERS, IN SPECIFIED YEARS

Year	Utilities using poles			Total
	Telephone and telegraph	Steam railroads	Electric railroads, light and power	
1906	2,395,722	254,268	924,676	3,574,666
1907	2,311,651	294,788	676,829	3,283,268
1908	2,562,239	155,418	531,497	3,249,154
1909	2,916,005	195,321	627,414	3,738,740
1910	(a)	(a)	(a)	3,870,694
1911	(a)	(a)	(a)	3,418,020
1915	1,680,880	966,962	1,430,122	4,077,964
1923	1,293,592	284,811	1,482,391	3,060,794
1925	1,456,017	220,636	1,604,861	3,281,514
1927	(a)	(a)	(a)	3,624,833
1929	2,400,511	280,901	1,875,483	4,556,895

(a) Segregated data not available.

Not all woods are suitable for pole timber. There are a number of requirements to be met pertaining to qualities such as strength, shape, weight, and durability. Also, producers must have sufficient stands available and production organized so as to be ready to serve the demand. It is important that the woods run of the timber be of uniform dimensions and that the taper, or its rate of change, be such that suitable distribution of wood throughout the pole is secured with a minimum of excess weight.

The use of metal spurs by linemen when climbing poles is an established practice, so on that account hardness is not a desirable quality for pole timber. Heaviness, of course, increases the cost of transporting and handling. Some timbers are unsuitable because of deformation which sometimes takes place with seasoning, causing derangement of the facilities carried by the pole line. The durability of such woods as chestnut and cedar in contact with the ground was generally known before the general use of poles and, no doubt, accounts for the early choice of these woods for pole usage. Later, the introduction of preservative treatment for pole timber brought about more utilization of wood not naturally so resistant to decay. The trend of this development in the use of pole timber in the United States is evident in Table 55, prepared from government publications (Bibliog. 92 and 93).

TABLE 55

NUMBER OF POLES PURCHASED IN U. S., BY KINDS OF WOOD, FOR SPECIFIED YEARS*

Year	Kind of wood								
	Cedar	Chestnut	Oak	Pine	Cypress	Redwood	Douglas fir	Others	Total
1906	2,174,279	988,084	9,924	177,809	111,657	(b)	(b)	112,913	3,574,666
1907	2,109,477	630,282	76,450	155,960	100,368	(b)	(b)	210,731	3,283,268
1908	2,200,130	516,049	160,702	116,749	90,579	(b)	(b)	164,936	3,249,154
1909	2,430,825	608,066	236,842	179,586	77,677	(b)	(b)	196,744	3,738,740
1910	2,431,567	677,517	265,290	184,677	75,459	(b)	(b)	236,184	3,870,694
1911	2,100,144	693,489	199,590	161,690	72,995	(b)	(b)	190,112	3,418,020
1915	2,521,769	651,643	199,442	546,233	67,644	(b)	(b)	91,233	4,077,964
1923	1,704,247	808,500	8,750	402,393	73,403	(b)	(b)	63,492	3,060,794
1925	1,692,870	776,263	5,541	675,730	101,720	5,227	10,166	13,997	3,281,514
1927	1,767,287	645,888	1,680	1,120,228	35,930	5,309	15,609	32,912	3,624,833
1929	2,095,293	503,888	6,179	1,865,424	25,540	4,704	44,748	11,119	4,556,895

(b) The number of redwood or Douglas fir poles reported purchased from 1906 to 1923, inclusive, was not segregated.

* Figures include reports from practically all large consumers of poles.

It will be noted in the above table that cedar, chestnut, and pine are the dominant pole timbers at the present time, and that the use of pine has increased greatly in recent years. These figures reflect the use of full-length pressure treatment for this timber. Douglas fir, only recently segregated, occupies fourth place in the number of poles purchased in 1929. Possibly most of these were full-length pressure treated before being placed in the ground, although there has been some use from commercial stocks of sawed fir by the smaller companies. On the Pacific Coast, cedar is by far the principal pole timber. In addition to cedar, in California, sawed redwood has for many years been employed to some extent. Recently, Douglas fir has gained some favor on the Pacific Coast. It is one of the stronger pole timbers, but has not been employed in pole line construction as a full-length treated timber long enough to establish its relative durability.

As with most other things, standardization of the methods employed in selecting pole timber makes for ultimate economy. In order to bring about such standardization for wood poles the American Standards Association has recently developed and published (Bibliog. 97, 101, 102, 103, and 104) tentative standard specifications and approved dimensions for the principal pole timbers. Also, this Association has approved standard values for the ultimate fiber stress of these poles. Briefly, these standards make it possible to order any of the pole timbers for a given duty after having determined the proper class of pole for any one of such timbers.

The extent to which decay affects the cost of construction and maintenance of pole lines depends upon a number of factors which differ with the class of circuits carried by these structures. In the State of California, proceeding under an act of the legislature, the Railroad Commission has prescribed rules for overhead electric line construction which fix the minimum strength requirements for various grades of communication, railway signal, supply, and electric railway pole lines. In some states the National Electrical Safety Code of the Department of Commerce has either been adopted by law or is used by public utilities as a guide. Also, the utilities themselves have certain standards of their own to meet, depending on and varying with the importance of the circuits, climatic, and other conditions, such as wind, sleet, and decay, the number and size of wires carried, etc. The duty the poles are required to perform differs with different users and for different lines of the same user.

Because statements about the "life" of poles arise frequently throughout an investigation of this kind, it is necessary to consider the possible meanings that attach to the word life when used in this connection. The thing of primary importance to the pole user is the "service-life," which is the length of time he can keep the pole in plant. "Physical life" is indirectly of interest because of its relation to the service-life. With a given service-life objective, as much or more physical life must be obtained; how much more depends on a number of things, such as rate of circuit growth, permanence in location, and others peculiar to each user. The physical life of a pole, therefore, depends not only on the durability of the wood and its resistance to decay, but on the strength which must be maintained, and this, we have seen, varies greatly under different conditions. The identical pole, therefore, has a different physical life under each condition of usage, even when the conditions with respect to decay are the same.

Because of these strength requirements, there is considerable good wood remaining in a pole when it is removed from plant, even though it be removed because of deterioration due to fungi and insect destruction. Generally, the *equivalent ground line circumference* is the criterion of the strength of the pole, and the physical life is considerably less than it would be were it possible to permit this minimum circumference to reach zero value.

In addition to the removals brought about by decay, poles are removed or replaced because of such other factors as inadequacy due to circuit growth, necessitating replacement with poles of greater dimensions; obsolescence due to advancements in the art; activities outside the field of the utilities, such as civic improvements and other public or private improvements causing changes and rearrangements of plant on streets, highways, and premises not under their control; fires, floods, and other casualties. Service-life is therefore not a simple relation between rate of decay and period of effectiveness of preservatives, and it is less than physical life, which we have seen is not controlled by decay only, but varies for other reasons, and, within limits, may be regulated by the engineer who designs the plant. It comes about, then, that the use of preservatives must be justified by each user on the basis of its effect on the service-life of his poles, and extended physical life may not always be desirable.

In the case of treated poles, the physical life may for practical purposes be assumed to be a combination of the life of the treatment plus the life provided by any excess of wood above the required minimum. Reduction in size of pole to compensate for the cost of treatment can only be practiced to a limited extent, because of structural requirements.

The points above have been discussed in considerable detail to show why different users may properly follow different practices. Thus, in cities where tall poles are required to provide wire clearance over streets, where frequent additions of circuits make for early inadequacy, where public improvements may force early rearrangement, and where appearance is an important factor, even the cost of butt treatment might not be warranted purely on the basis of extended life, and the considerable extra cost of full-length treatment would, of course, be still more difficult to justify. On the other hand, on permanent railroad right-of-way, short signal poles provide sufficient clearance and the circuit load is fairly constant, so that service-life more nearly approaches physical life, and not only might butt treatment be indicated, but the relatively small extra cost of full-length treatment might be properly assumed. The whole matter as to when either butt or full-length treatment can be justified on a cost basis appears to be one that must be answered by each user according to the conditions under which his plant is operated, and he is able to make this determination from the service-life performance in his plant, provided the period of effectiveness of preservative treatment is known, as well as the rate at which untreated timber decays.

With regard to crossarm timber, it may be stated that southern pine (creosoted) and Douglas fir (untreated) are usually employed. A great many crossarms are employed under conditions where either kind could be used with little difference in the service-life, so that the choice between them is made on the basis of delivered costs. There are, of course, climatic and other conditions under which one type of arm will be more desirable than the other, and these may be such that untreated crossarms should not be used. For example, treated crossarms may be indicated where lines are on permanent right-of-way and service requirements relatively static, or where the rate of decay is high and the dry-wood termite is a serious menace. Where these conditions hold and Douglas fir is more readily available than southern pine, creosoted Douglas fir crossarms are frequently used to good advantage.

HISTORICAL REVIEW OF EFFORTS TO RETARD DECAY OF POLES AND CROSSARMS AND THE RELATION OF TERMITES TO THIS PROBLEM

As previously stated, the industries interested in the use of pole timber have for many years been engaged in the study of the problem of extending the useful life of their properties, and the various possible methods have been thoroughly investigated and suitable means have been developed and put into practice. Appendix B (p. 666) is a bibliography which includes publications relating to pole preservation, and it provides an index of reports covering some of the earlier work done in this connection.

While the foregoing expresses the general situation, it is entirely possible that there are localities where some users have not yet adopted what appear to be the best practices. This is a detail that time will care for, and investigations like the present one help to clarify some of the uncertainties.

It will be noted that many of the earlier publications listed in Appendix B emanate from studies made abroad and from research conducted in this country by the steam railroads and governmental agencies. Study of preservative treatment with particular reference to wooden poles began some thirty-five or forty years ago, at which time pole practice in this country was based upon the use of species of timber possessing high resistance to decay when placed in contact with the soil. The telephone group began experimental installations prior to the year 1900 and later inaugurated others, some of which are still under observation. Reports from these installations have been published on two or three occasions (Bibliog. 61, 62, and 78) and will be mentioned in this review. Through the courtesy of the American Telephone and Telegraph Company an unpublished report of their observations, dated August 3, 1931, has been obtained by the Committee and permission received to include it as part of this section (Appendix A, p. 635).

It is of interest to state, as will be noted later, that insects, including termites, were recognized throughout this period as being in the group of destructive agencies with which these investigations were concerned.

The National Electric Light Association (Bibliog. 61), representing the electric light and power companies of the country, in 1909, through its committee on Overhead Line Construction, reported that the subject of preservative treatment of wood poles and crossarms appeared to be one of great importance to the member companies, and recommended that the entire matter be taken up during the coming year by a special committee and be made the subject of an exhaustive report. During the following two years this special committee made a very thorough study and wrote comprehensive reports which appeared in the annual reports of the Association (*N.E.L.A. 33rd Convention,* May, 1910, vol. 1, pp. 230–350; *N.E.L.A. 34th Convention,* May 1911, vol. II, pp. 579–700).

In gathering information for the 1910 report, the committee issued a circular containing sixty questions pertaining to the methods of handling poles and crossarms and the experiences the member companies had had with preservative treatments of poles and crossarms. Replies were received from 165 member companies, 9 of which were operating in California. This report lays practically all pole deterioration to decay and gives but slight recognition to termites as an agency of damage, the only mention being the following: "One thing is apparently certain and that is that the life of a pole is practically dependent upon its decay-resisting qualities. The United States Department of Agriculture (Forest Service Bulletin No. 78) estimates that, for poles, 95 per cent are destroyed by decay, 4 per cent by insects, and only 1 per cent by mechanical abrasion."

There are two other features of the pole situation, namely, the average "life" of untreated poles and the preservative treatment of poles, upon which this 1910 report should be quoted for the sake of later comparison with the 1931 point of view. On the subject of pole life it says:

> The average life of an untreated seasoned pole depends so much upon the kind of timber, its condition when set, the character of the soil, and the climatic conditions, and these are all so variable, that a definite statement as to the average life is difficult. Most companies can closely estimate the average life of their poles, as controlled by local conditions, by referring to their pole records. The average throughout the country, however, is apparently somewhat as follows: Cedar, 13½ years; Chestnut, 12 years; Cypress, 9 years; Pine, 6½ years; Juniper, 8½ years.

In view of the source of these figures, they doubtless represent service-life rather than physical life. Even today, as will appear later, few, if any, companies maintain records of other than service-life. It should also be noted that the above averages carry no conclusions regarding the relative merits of timbers from different sources, such, for example, as northern white cedar and western red cedar.

In regard to the preservative treatment of poles the committee writes in the conclusion of this report as follows:

> Your Committee investigating this subject met with many difficulties in trying to reconcile the diversified opinions now prevalent in the preservative field. It was decided, therefore, to make treatment recommendations somewhat general. In spite of the full and admirable literature on the subject of wood preservation, both as a whole and bearing in detail on some of its special phases, it is still remarkable that unanimous authoritative opinions can be obtained only on the more elementary features; and it is peculiarly difficult to secure information that will afford an adequate and accurate comparison of the different classes of preservatives and preservative processes.
>
> Your Committee feels that "caution" should be the foreword of this report. A personal investigation undertaken by some members of the committee revealed the fact that the whole preservative field is in a state of uncertainty. In a general way it now presents a scene of conflicting commercial interests and contradictory opinions. This condition exists not only among competitive preservative companies, but also among the recognized and so-called preservative authorities and the many people who are either directly or indirectly interested in the business. Some fraud has been practiced, and it has been known for some of the treating companies to charge for much heavier injections than were actually given to the timber. Consumers have suffered not only as a result of fraudulent practice, but also from the ignorant methods of some of the companies. Some of the latter, although not guilty of intentional dishonesty, have caused a loss to their customers by the use of an inferior quality of preservatives, loose methods of measuring the preservative injected, or by defective apparatus and ignorance or carelessness of employees.
>
> Owing to the unquestionable merit of proper preservative treatment, it is felt by your Committee that even such abuses in the trade will not eventually destroy confidence, because time, which is really the controlling factor in this question, will accomplish at least two things: It will point out the lasting benefits accruing from those treatments where proper selection was made and honest work done, and likewise will eventually reveal the results of improper selection and will identify fraudulent work. This one all-necessary element of time seems to be the temporary protection for those treatment companies which are either negligent or dishonest in their work, and it likewise shields the inferior preservatives that are now sold through the extravagant claims made by their manufacturers.

In reading the conclusion reached by the Association's committee, one should not forget that their report was written over twenty years ago. The condition they reported does not obtain today where there is an effort at cooperation between user and supplier.

The committee's section on preservatives is introduced by a discussion of wood anatomy and the mechanism of decay. This is followed by a discussion of preservative agents, such as oils, coal-tar creosote, water-gas tar creosote, petroleum oil, wood creosotes, and salts. The following excerpts from this section will be of interest.

> Before considering the action of preservatives, it may be well to emphasize these axioms:
>
> Decay is induced by the action of living organisms.
>
> Moisture, air, food, and a certain amount of heat are absolutely necessary for the growth of these organisms.
>
> Perfectly dry wood will not decay.
>
> Wood kept under water will not decay.
>
> Wood saturated with a substance which will act as a germicide will not decay.
>
> Wood saturated with a substance which will act as an antiseptic will not decay.....
>
> Whatever difference of opinion may exist in the minds of those interested in the subject as to the relative merits of other preservatives, one and all agree that coal-tar creosote oil, when properly applied, will protect timber against decay for an indefinite period, usually far in excess of its mechanical life, and it is therefore regarded as the ideal preservative and a standard by which all others must be gauged. The reason for this is due primarily to the fact that time, the all-important factor in the field of wood preservation, has demonstrated its value under most variable and trying conditions.....
>
> The choice of the proper preservative is dependent, in a great measure, upon local conditions, and therefore no definite recommendations can be made. It is our opinion that full-cell treatments, with a high grade creosote oil, will insure the maximum protection, but it is by no means uncertain that full-cell treatments with petroleum oil or other heavy oils will not *offer an equal amount of protection. The chief danger of employing such oil would lie in* not using it in quantities sufficient to keep out moisture or air.
>
> It would seem that an entirely satisfactory oil, having antiseptic qualities, can be obtained from the distillation of water-gas tar, and as this material may be readily obtained, its general use would do much toward solving the difficulty of obtaining suitable oils at a reasonable cost.

The latter conclusion would not receive general endorsement today, since there now exists some doubt as to the general efficacy of water-gas tar oils. The report continues:

> While from a theoretical standpoint the use of metallic salts cannot be recommended for poles and crossarms on account of their solubility, still, in view of the exceptional results obtained in Germany by the use of copper sulphate and mercuric chloride, the Committee is not prepared to say that these cannot, at times, be used to great advantage. It recommends, however, when salt treatments are employed, that they be protected against leaching by creosote or some such similar method, and also that due caution be exercised in choosing this method of treatment.
>
> Since much of the treating which will be done for the members of the National Electric Light Association is likely to be by the open-tank process, special attention should be paid

to specifications covering suitable oils, it being remembered that a large part of the oil distilling under 200° Centigrade is likely to be lost by volatilization during the process of treatment, thus greatly increasing the cost. The oil to be used in the open tank should constitute the higher boiling portions of the tar.

A report dated March 28, 1910, on some of the experimental lines covered in our Appendix A was included in the 1910 report and contained the following statement:

> Pole removals have been made in this line from time to time. The bulk of these changes have been made on account of changes in the line. About fifty poles have been removed on account of decay; that is, less than one-half of 1 per cent of the poles have been removed for that cause after a service of about thirteen years. The remainder of the poles in this line are in first-class condition today and will give many years of additional service.

In the 1911 report of the committee they state that they were particularly anxious to collect full information concerning the extent of damage to poles by wood-boring insects, but that in the course of their search for such information the committee did not find a better treatment than that contained in Circular No. 134 of the Bureau of Entomology, U. S. Department of Agriculture. In a reprint of this circular, under the heading "Injury by Other Insects," the following statement is made:

> It is not to be concluded that injury by the pole-borer is the only type of insect damage to poles. Indeed, a very common injury is by white ants, or termites. In lines from 10 to 12 years old serious damage by these insects occurred in as high as 15 per cent of the poles, and their work is often present, at least superficially, in as high as 75 per cent of the poles under all conditions of site. The damage, however, is usually to the outer layers of the wood, where it is moist and there is incipient decay, and is more superficial and localized than that of the pole-borer. Nevertheless, the sound heartwood of poles is often completely honey-combed, especially at the base. The work of the white ants is found both in sound wood, "doty" wood, and "sobby" wood. Sometimes a large channel runs up through the core of the heart and the sides are plastered with clay, forming a hollow tube with several longitudinal interior galleries. Their work often extends from 2 to 4 feet above the surface of the ground. They leave the outer shell of the wood intact and work up through the longitudinal weathering checks, covering the exterior of the pole with earth to exclude the light. White ants will damage poles that have been set in the ground only two years. Evidently they enter the poles from below the ground.

Then under the heading "Possibilities of Preventing Damage to Poles" this circular says:

> Method of treating poles superficially by brushing with various preservatives have proved to be temporarily efficient in keeping out wood-boring insects, if the work is thoroughly done and not only the butt, but also the basal area, is treated. If the pole is not thoroughly brushed, the pole-borer and other insects enter through the untreated or imperfectly treated portions, especially through weathering checks and knots. Where the base is left untreated, insects, especially white ants, or termites, enter the pole from below ground, and, avoiding the treated portions, come right up through the pole.

The present view regarding the efficiency of brush treatment for new poles is discussed in the section herein under the heading, "Present View of Distribution and Destructiveness of Termites." The circular continues:

> Impregnating the poles with creosote by some standard process (either by the open-tank or by a cylinder-pressure process) will keep out wood-boring insects. In the open-tank method only the area most subject to the attacks of wood-boring insects (*i. e.*, the basal 8 feet) is treated, while by the cylinder-pressure process the entire pole is impregnated.
>
> Therefore, to effectually protect poles *from the depredations of wood-boring insects it is* recommended that they be impregnated with creosote by either the open-tank process or by the cylinder-pressure process.

The 1913 report of the National Electric Light Association contains a paper on "Poles and Pole Preservation" presented before the Hydro-Electric and Transmission Session by Mr. R. A. Griffin, who says:

> Only those woods which are the most durable after the trees are cut are used for poles—durability in wood meaning the length of time which it remains serviceable as a consequence of the sound condition of its fiber and its freedom from decay. . . . . By the decay of timber we mean the change from the sound or perfect condition to an inferior state. It is now known that decay is caused by the activity of lower forms of animal and plant life. The living organisms which cause the decay of wood may be insects, bacteria, or fungi. Insects bore into the sound wood and sometimes so riddle it that it falls to pieces. These insects, such as beetles and white ants, are particularly active in the hot climates, and the teredo abound in southern waters; but decay in the sense in which it is usually understood is caused by bacteria or fungi.

Nothing further in regard to termites and very little in regard to pole preservation appeared in the annual reports of the National Electric Light Association until 1920. In the meantime, in 1915, information gathered by the telephone group of pole users was presented by F. L. Rhodes and R. F. Hosford at a meeting of the American Institute of Electrical Engineers (Bibliog. 78). The following abstract preceded the introduction of the published report:

> The results of an experience with treated poles over a period of 18 years have been analyzed. Data are given for poles treated by pressure, open-tank, and brush methods. The relation of these methods of treatments to the conditions which have determiend the choice of pole timbers in the United States is outlined. The experience with brush treatments has reached a more advanced stage than that with the other types of treatments and is consequently discussed in greater detail. Rates of decay, increase in life by treatment, the effect of seasoning, and the characteristics of the damage to poles caused by decay and by insects, are all covered.

Since these installations will be discussed further in connection with later reports and in Appendix A, it will be sufficient at this time to establish the fact that these observers were fully aware of the part played by insects, including termites, in the general problem of wood preservation. We read from the report:

> For many years insects have been found in decaying poles but it is only recently that systematic study of insect damage to poles has been attempted. The study of this problem was proposed in 1910 by Dr. A. D. Hopkins of the Bureau of Entomology, whose assistant, Mr. T. E. Snyder, had just completed the investigation of a case where a wood-boring beetle (*Parandra brunnea*) had been found causing serious injury to a pole line. The inspection of the experiments with butt treated poles was, at that time, just becoming active. Through the participation of Mr. Snyder in one of the early inspections, a founda-

> tion was laid for future work through the training of the inspection force in methods for gathering data bearing on insect damage. Through following these methods, and with the assistance afforded by the Bureau of Entomology in identifying specimens collected by inspectors, a valuable record of insect damage as affecting the experimental poles has been gathered.
>
> Substantial insect damage has come from two very different sources. *Termites, or white ants,* as they are often referred to colloquially, *have long been recognized** as a source of injury to timber, particularly in the South, where the warm climate is favorable to their prevalence. The damage caused by the wood-boring larvae of beetles has only recently received recognition. Both of these classes of insect are fairly common causes of damage to pole timber, and data as to the effect upon their incidence of methods of preparing and treating poles are therefore worthy of attention.

Other remarks of interest are as follows:

> The principal insect damage found upon the poles placed in the Savannah-Meldrim line was due to termites. A few cases of attack by termites were also noticed when the Omaha-Denver line was examined. In a number of cases termites were found in small decayed spots where initial failure of a brush treated pole had taken place. . . . . No direct evidence was obtainable as to whether the decay-producing organism or the termites first entered such poles. . . . . The indications are, therefore, that treatment retards the attack of termites, and that the retardation is probably due to delaying the beginning of decay. . . . . Mechanical failure of the treated layer is indicated as the principal limit to the effectiveness of light applications of preservatives.

In the 1920 report of the National Electric Light Association the committee on Preservative Treatment of Poles and Crossarms again brings its findings up to date. We read:

> In this section is given a digest of member companies' replies to a questionnaire issued by this Committee; also some specifications and data which should be of interest and use to member companies desiring to decide upon proper practices for their respective conditions. The process and preservative to be used by any company should be determined upon only after a careful analysis of the local plant conditions. The treatment profitable to one company might give discouraging and unprofitable results to a company differently situated. The climate, the species of timber, the method of treatment, the preservative used, the plant layout, and other controlling factors necessitate diversified practices in order to meet the various requirements found throughout the country.

It is of interest to note the extent to which pole treatments were being used at that time. Out of the 65 electric light and power companies answering the committee's questionnaire, 38 indicated that they were using poles treated in some manner with coal-tar creosote or a similar product, the brush treatment being the most popular. There is included in this report a statement from the Western Union Telegraph Company saying, "For quite a number of years it has been the general practice of the Telegraph Company to apply a brush treatment of coal-tar creosote to the majority of its poles at the time they are set." Also the inclusion of the American Telephone and Telegraph Company's specification for the open-tank butt treatment of poles with coal-tar creosote indicates that that company was using the butt treatment at that time.

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* Ed. Note: The italics are ours.

Throughout the report there is no mention of termites, although "rot," "decay," "fungi," and "other defects" are frequently mentioned. Apparently, termites were not considered sufficiently important to receive specific mention.

In the 1921 volume of the National Electric Light Association the committee on Preservative Treatment of Poles continues with technical information on treating plants and methods, including the process of puncturing or perforating pole butts in order to secure better penetration of preservatives, particularly in the case of poles resistive to treatment. The important thing in this volume is a report on "Service Tests of Treated and Untreated Poles" by P. R. Hicks, which covers experimental poles placed in 1905 and 1910 by the American Telephone and Telegraph Company, and in 1908 by various telephone and electrical companies in southern California, in cooperation with the Forest Service. Besides giving a later view of the experiments described in the 1915 A. I. E. E. Proceedings, this report also covers experimental poles installed in Los Angeles. In this report, results are given for open-tank treatment with creosote, brush treatment with creosote or carbolineum, brush treatment with other preservatives, and no treatment.

Because of the very general use of western red cedar in the Pacific States, pole users on this coast were particularly interested in the Los Angeles tests, where the experiments on this kind of timber were conducted. Speaking of these tests, a committee of the Pacific Coast Electrical Association, reporting on "Life of Treated and Untreated Poles," in 1926, has this to say:

> This is the most valuable and authentic record we have on this matter, as the experiment has been under the direction of government experts from the beginning and most careful records of seasoning, treating, inspections, etc., have been kept.

On the whole, the various treatments gave results decreasing in effectiveness in the order named above, and since it was about this time that the use of creosote butt treated poles was considerably extended, it is of interest to show what the tests exhibited for creosote butt treated and for untreated poles. Since the details, except for western red cedar, are given in Appendix A, the following tabulation, with that exception, has been prepared from the latter exhibit. The results shown are for the poles remaining after deleting those replaced or dropped from the record for causes other than decay. Three groups of untreated eastern cedar not covered by Mr. Hicks's report are included here.

For the poles open-tank treated with creosote, the condition was as shown in Table 56.

TABLE 56

Location	Kind of wood	Years service	Per cent	
			Sound	Partly decayed
Buffalo, N. Y., to Warren, Pa.	Chestnut	14	94.4	5.6
Los Angeles, Calif.	Western red cedar	11	93.1	6.9
Omaha, Neb., to Denver, Colo.	Chestnut	10	82.0	16.8
Omaha, Neb., to Denver, Colo.	Eastern cedar	10	98.8	1.1

The condition of the untreated poles is given in Table 57.

TABLE 57

Location	Kind of wood	Years service	Per cent removed on account of decay	Circumference loss per year in inches
Buffalo, N. Y., to Warren, Pa.	Chestnut	14	2.2	.29
Savannah, Ga., to Meldrim, Ga.	Juniper	14	95.9	1.68
Savannah, Ga., to Meldrim, Ga.	Chestnut	14	73.9	1.33
Los Angeles, Calif.	Western red cedar	11	39.2	1.02*
Omaha, Neb., to Denver, Colo.	Chestnut	10	36.0	1.07
Omaha, Neb., to Denver, Colo.	Eastern cedar	10	29.0	.66

* In Mr. Hicks's report the loss in circumference was not given in inches, so the figures for western red cedar marked by the asterisk, have been computed by multiplying average original circumference by the per cent loss per year, both of which were given.

The conclusions to which analysis of these reports pointed are well expressed in the next annual report of the National Electric Light Association, to which reference will be made shortly. Attention is called to the following statement, which illustrates that design plays a considerable part in the life obtained from poles.

> The replacement circumference of the experimental poles varies according to the species, the number of poles per mile, the wire load, the length of the pole, and the location and importance of the line. In the Buffalo-Warren line all the poles were 30-foot chestnut. Some of them carried 16 wires and others up to 26 wires. They were marked for replacement when the circumference of the sound wood at the point of greatest decay was found to be from 21½ inches to 24½ inches, respectively. The replacement circumference of the 30-foot chestnut poles in the Savannah-Meldrim line, carrying 14 to 28 wires, was taken as 20 inches to 23 inches compared with 19½ inches to 23 inches for the 30-foot chestnut poles in the Omaha-Denver line, which carried 12 to 20 wires. . . . .

In Mr. Hicks's conclusion and remarks, he says:

> In analyzing the above data and in comparing the results obtained with treated and untreated poles it must be kept in mind that, because of climatic conditions in Georgia and Southern California, the experimental poles set in these locations are subjected to decay throughout the entire year, while the poles in Nebraska and New York have some respite during the winter.

After paying heed to this warning, there seem to be no data exhibited which show that the Los Angeles untreated poles or creosote tank-treated poles compared unfavorably with those in the other locations, and the report furnishes no special grounds for alarm on account of termite activity, since no mention is made of them, notwithstanding that the method of inspection on this test calls for removal of all portions of wood "destroyed by insects."

In 1922, under the head "Results Secured from Preservative Treatment of Poles," the Overhead Systems Committee, speaking of the Rhodes-Hosford and Hicks reports, says:

> These reports prove conclusively that poles properly treated with creosote have many years added to their life, and their careful study is recommended to all companies not now treating their poles.

> Based on the performance of these and other experimental lines, it is conservatively estimated that a hot and cold open-tank treatment satisfying the requirements of the American Telephone and Telegraph Company's "Specifications for the Butt Treatment of Poles," printed on p. 810 (Proc.) of the 1921 Report of this Committee, will extend the pole life an average of approximately 10 years.....
>
> ....the Committee wishes to emphasize the increasing importance of treating poles in order to conserve the supply and in order to reduce maintenance costs in the future.

In this report, also, Mr. Hicks continued his presentation of test results on pole preservation, paying particular attention this time to full-length pressure creosoted pine poles. He says, "Creosoted pine poles are in use not only throughout the South, but in northern states as well, among them Nebraska, Iowa, Illinois, Indiana, New York, and Pennsylvania."

In this volume, for the first time, do the reports of the National Electric Light Association reflect any particular concern on the part of the power companies in regard to the damage done to pole lines by termites. Under the heading "Destruction of Poles by Termites" we read:

> Recently the attention of the Committee has been called to the ravages of termites, or white ants, in wood poles. It has long been known that termites occur widely throughout this country, especially in the South, but the fact that the distribution structures of power companies might be seriously affected has perhaps not been appreciated. During the past two years the southern California companies have suddenly awakened to the fact that much of the pole deterioration which has loosely been termed 'rot' is not really fungus rot at all, but is in fact caused by the activities of termites. There is no reason to believe that this is a recent phenomenon; on the contrary, it has only lately been properly noted.

In view of the amount of information previously made available, it is not clear why the southern California companies are charged with this lack of understanding. Possibly the poles were properly spoken of as decayed, meaning to include termites, if any. The supporting evidence provided in the report emanates from two power companies. These reports are to the effect that a large percentage of untreated poles or poles brush treated prior to 1916 (probably butts only) were affected, but that very few tank treated poles were so affected. There follows, then, a very concise and temperate article by Dr. T. E. Snyder, Specialist in Forest Entomology, United States Department of Agriculture, describing termites and their habits. This article makes clear the distinction between problems of pole butt damage and pole top damage as affected, respectively, by the species of *Reticulitermes,* which attack from below the ground line, and the species of *Kalotermes,* which attack the pole directly and do not live in the ground nor require ground connection. Dr. Snyder also states that open-tank butt treatment is a sufficient preservative *except where damage by Kalotermes is severe.*[*] He also says that full-length treatment *may* be advisable in southern California and the Southern and Gulf States.

The 1926 annual report of the National Electric Light Association prints results of later inspections of the experimental lines previously discussed by

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[*] Ed. Note: The italics are ours.

P. R. Hicks. The discussion this time is written by R. M. Wirka, of the United States Forest Products Laboratory, Madison, Wisconsin. The results for the Los Angeles test showed that after 16 years' service, 75 per cent of the poles open-tank treated with creosote were still sound, and 23 per cent only partially decayed.

An item that might be mentioned here is a statement made under the heading, "Southern California—Western Red Cedar," as follows:

> A factor which seems to be at least equal in importance to decay in affecting the life of untreated and butt treated poles in Southern California is the attack of termites in the untreated areas. A high percentage of the experimental poles are so affected to a greater or less extent. . . . . From the results of the inspections and observations it is believed that a high percentage of the butt creosoted poles will eventually be removed, not on account of decay at and near the ground line, but on account of termite attack above this area. It is quite likely that the same will be true for the poles butt treated with zinc chloride and zinc creosote, but most of the untreated and brush treated poles will probably be removed on account of decay or a combination of decay and termite depredation.

As a matter of fact, all of these poles, so far as it can now be determined, were removed because they were no longer adequate for the service and not because of physical deterioration, although some of them were fully deteriorated. The report continues:

> With the termites as active as they are at the present time in Southern California, the consumer will be practicing poor economy if he uses a good butt treatment such as the open-tank creosote treatment for instance, and fails to provide protection for the top. If, however, only a brush treatment of the butt is used, it appears a mere extravagance to treat the tops, as the butts will probably be rotted through before or at least as soon as the top is severely damaged by termites.

The above is the only reference to termites in these Forest Products Laboratory reports.

In the 1927 National Electric Light Association report, the destruction of poles by termites is again considered, and the committee stresses the point that the distribution of these pests is probably more widespread than is usually recognized. It further states:

> In the experience of one member company untreated thirty-five foot western red cedar poles have become so weakened by termites in five years as to require replacement. . . . . The weakening of poles is not due entirely to the eating of wood substances by the termites, although this is a serious contributing cause, but also to decay for which the termites are responsible.

Next is described how the fungus spores are carried into the poles by the termites and it is stated that this applies principally to those termites which maintain contact with the ground. It states further:

> It is claimed that several wood-preserving salts prevent termite attack, but the most universally accepted preventive against it is creosote. So far as is known, termites have not attacked a creosoted pole by eating their way through creosote, but where a creosoted pole has been attacked, access has been gained through a check or other opening and the treated wood avoided.

In the 1928 annual report of the National Electric Light Association, Mr. R. M. Wirka gives the results of the 1925–1926 inspection of the Warren-Buffalo line and the 1926 inspection of the Omaha-Denver line. His conclusions are:

> The results of the latest inspections of the Warren-Buffalo and Omaha-Denver lines seem to warrant the following general conclusions:
>
> Seasoning poles before setting is unnecessary if they are to be used untreated.
>
> The open-tank hot and cold bath butt treatment with creosote is more effective than brush treatments.
>
> A two-coat brush treatment is better than a single coat with the same preservative.
>
> The average life of untreated seasoned cedar poles in the Omaha-Denver line will be only slightly longer than that of untreated seasoned chestnut.
>
> In the regions over which the Warren-Buffalo and Omaha-Denver lines extend, a top treatment is not necessary to avoid the premature removal of cedar or chestnut poles because of decay in the tops. The results to date indicate that the experimental poles will be removed on account of decay in the butts.

In the 1926 Proceedings of the Pacific Coast Electrical Association (Bibliog. 91) the report of the subcommittee on the "Study of Life of Treated and Untreated Poles" contains, among other things, the results of detailed examinations of particular sections of pole lines on the systems of seven California power companies. From these statements the subcommittee writes the following under "Conclusions and Recommendations":

> For the purpose of this report, it will be considered that the life of a pole has ended when it is necessary to spend money to continue it in service.
>
> From reports given above it appears that the life of untreated western red cedar poles in most locations has been from 10 to 15 years and for butt treated poles from 15 to 20 years. No doubt in districts where termite attack is more severe, if the rule were followed of replacing the pole when its safety factor has been reduced to two-thirds of the minimum required for its respective grade of construction, it would be found that the lower figure in each case is about the average life. The conclusion, therefore, is quite obvious. In locations infested with termites a full-length treated pole should be used.

It does not appear in the above whether it is service-life or physical life that has the given values. Assuming physical life is under discussion, other analysts do not find in the reports of the seven power companies a basis for all of these conclusions as to life of poles and necessity for full-length treatment, except where dry-wood termites are active in pole tops. It is pointed out that possibly the reason for this low estimate is that two of the companies reporting set ten years or ten years plus as the remaining life of poles already seven to nine years old and having treated butts in good condition. It is reasonable to assme that these were limits beyond which these companies did not care to guess. The only butt treated poles cited that are old enough to throw any light on this question (those of the San Joaquin Light and Power Corporation) indicate that the average life should be about thirty years, but it does not take into account heavy termite attack in the tops of the poles. It is also felt that the information given does not justify an average life assumption for the untreated cedar poles of less than fifteen years.

This same subcommittee, in the 1927 proceedings, gives some interesting information on the life of western red cedar poles. Under the heading "Life of Poles" it says:

> Supplementing the work and report of this subcommittee for 1925–1926, some additional data relating to the life of treated and untreated western red cedar poles have been obtained.
>
> The Railroad Commission of California made a study of portions of the Pacific Gas and Electric Company's system and arrived at an average life for 40-foot and 45-foot cedar poles of:
>
> | | |
> |---|---|
> | For untreated poles | 19 years |
> | For creosoted butt treated poles | 27 years |
>
> Larger poles have longer lives and smaller poles shorter lives than the above.

It is assumed that physical life is meant here, which, as has been shown, depends on the duty expected of the pole; and so it must have been a peculiarity of the company's design which gave larger poles longer lives. Possibly the poles were not loaded in proportion to their size.

The report goes on to say:

> The Southern Sierras Power Company working with representatives of the Railroad Commission conducted a careful survey of the condition of wood poles on all parts of its system, extending from Mono Lake in the east central portion of California to the Mexican border and east to Yuma. . . . . The study was confined to poles set prior to 1921. . . . .

After describing the method of making the survey the report goes on to state:

> Of all the poles examined, 17 per cent were found infested with termites of which 82 per cent were untreated and 18 per cent treated. In the central district, however, 31 per cent of the poles were infested. None were found north of Bishop and comparatively few in the southern valleys. (The "central district" is defined as comprising the territory south of the mountains and west of Banning.)

Table 58 gives the essential data and resulting estimated life of poles on this system as given in the report.

TABLE 58

	Treated poles	Untreated poles
Number examined	209	138
Total on system	40,584	3,061
Average age examined	10 years	14.7 years
Average age on system	6.3 years	14.7 years
Estimated average to stubbing	28 years	17 years
Total life	35 years	27 years

It should be noted that the total life is figured on the assumption that the poles will be stubbed once. The report goes on to say:

> For the purpose of studying the reduction of pole strength by termites, particularly the species (*Kalotermes*) which work in the upper dry portions of the pole, a badly infested pole was removed from a line near Riverside and cut into 4-foot sections, which were then split longitudinally. *Although channels and live termites were found throughout the entire*

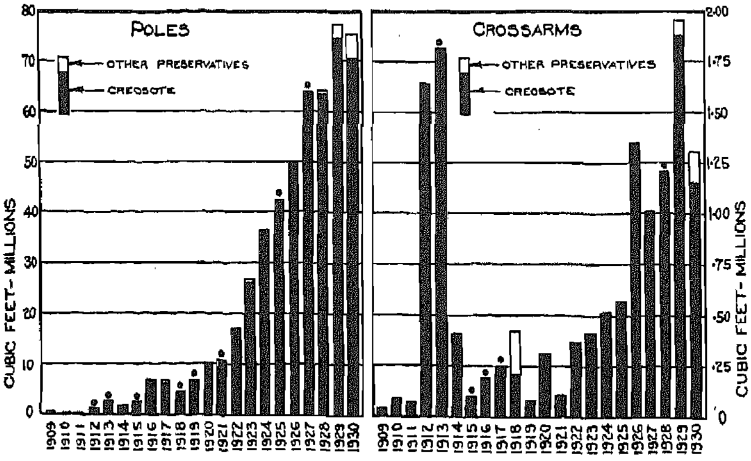
> *length of the pole in both sapwood and heartwood, the only point where the pole was materially weakened was near the ground line and at the crossarm gain.** At the latter point approximately 5 per cent of the pole section was eaten away, and the effective strength for support of arm was estimated to be reduced approximately 15 per cent, although no means of determining the reduction of strength with any degree of accuracy seems to be available.

The committee then devotes some space to experiments in treating old poles in place to rid them of termites, and to various methods of treating poles before installation.

During 1928 the Termite Investigations Committee was formed in California, and since that time all of the pole-using companies of the Pacific Coast have been working with that Committee on the termite problem. The few comments on termites that appear in the publications of the National Electric Light Association and the Pacific Coast Electrical Association are the results of work done in connection with this Committee, and so need not be mentioned in this historical review, which was intended merely to give a picture of the situation as understood by the pole users up to the time of the formation of the Termite Investigations Committee.

A measure of the extent to which the results of all these investigations, conducted over the past thirty or more years, have been reflected in practices regarding the selection of poles and the use of preservatives, is obtained by reference to statistical reports on the quantity of poles and crossarms treated and of preservatives used in the United States.

In this connection the following chart and tables have been prepared from published reports. (Bibliog. 96)



● OTHER PRESERVATIVES—QUANTITY TOO SMALL TO SHOW TO SCALE
TO OBTAIN NUMBER OF POLES DIVIDE THE FIGURES SHOWN BY 17·6
TO OBTAIN NUMBER OF CROSSARMS DIVIDE THE FIGURES SHOWN BY ·6198

Fig. 169. Poles and crossarms treated in the United States in specified years.

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* Ed. Note: The italics are ours.

It will be noted that creosote is now by far the dominant preservative in point of usage. In the last few years some little use has been made of creosote-petroleum mixtures, in regard to which we read in Mr. E. G. Helphenstine's report that petroleum is used in mixture with creosote as a diluent and is employed mainly in the treatment of crossties.

It is interesting to note the relatively large amount of miscellaneous preservatives reported for 1929 and 1930 as compared with other years. There was a large increase in the amount of salts reported for all uses during these two years, but the extent to which these salts were applied to poles or crossarms is not shown.

It appears that creosote is practically the only preservative used to treat crossarms. Of the treated crossarms reported, 84 per cent are southern pine and the balance Douglas fir.

As would be expected, in view of the ease with which they may be treated and their relatively low natural resistance to decay, southern pine poles are practically all full-length pressure treated, while western red cedar, northern white cedar, and chestnut poles, being naturally resistant to decay, particularly above ground, are practically all open-tank butt treated only.

Data on the quantity of poles purchased in 1930 are not available, but for 1929, as shown in Tables 54 and 55, the number was 4,556,895. Table 59 shows that 4,276,031 poles, over 93 per cent of the number purchased, were given either a pressure-cylinder or non-pressure (open-tank) treatment. Table 60 shows that over 57 per cent of those treated received a pressure treatment, but when the Pacific Coast alone is considered, less than 7 per cent of those treated received a pressure treatment. This, of course, is because the production on the Pacific Coast is largely western cedar, while there is a large production of full-length treated southern pine on the Southern Coast, which affects the totals.

Data on the production of crossarms are not available, but Table 60 shows that over 84 per cent of those treated received pressure treatment, while less than 3 per cent of those treated on the Pacific Coast received pressure treatment. Here, again, the yellow southern pine crossarms are not a product of the Pacific Coast, where the local supply is Douglas fir.

PRESENT VIEW OF DISTRIBUTION AND DESTRUCTIVENESS OF TERMITES

Biological information concerning termites and the work they do in poles and other timber is given elsewhere in this volume and in other publications, including those sponsored by this Committee (Bibliog. 99). The economically important types of termites in California are discussed and their distribution given. Their dependence upon suitable temperature and moisture conditions is explained, so that it is possible to determine the probable degree of activity and, consequently, the destructiveness of each type for any locality.

Briefly, we are now concerned here with three groups, which have been named as follows:

1. Damp-wood (rotten-wood) termites
2. Dry-wood (sound-wood) termites
3. Subterranean termites

The dry-wood and subterranean termites are our chief concern in California, because the damp-wood type does not destroy sound wood to a great extent. The work of the damp-wood termite in other states is discussed in another section of the report.

TABLE 59

NUMBER OF POLES TREATED IN U. S., BY KINDS OF WOOD AND KINDS OF TREATMENT, 1930

Kind of wood	Full-length pressure treatment	Butt treatment only	Total
Southern pine	2,428,001	(1) 172	2,428,173
Cedar—			
western red	11,073	1,114,422	1,125,495
northern white	28	425,026	425,054
Chestnut	....	188,958	188,958
Lodgepole pine	8,983	87,374	96,357
Douglas fir	10,719	1,209	11,928
Miscellaneous	....	66	66
Total	2,458,804	1,817,227	4,276,031

(1) Experimental treatment

TABLE 60

PRESSURE AND NON-PRESSURE TREATED POLES AND TREATED CROSSARMS BY REGIONS IN THE UNITED STATES—1930

Regions	Poles		Crossarms	
	Pressure treatment (number)	Non-pressure treatment (number)	Pressure treatment (number)	Non-pressure treatment (number)
Atlantic coast	52,741	158,641	176,778	52,816
Southern coast	2,307,726	69,519	1,587,184	....
Interior eastern	67,998	1,061,349	4,408	38,090
Interior western	8,983	232,279	....	2,042
Pacific coast	21,356	205,439	6,150	228,766
Total	2,458,804	1,817,227	1,774,520	321,714

The map in figure 59*a* indicates that subterranean termites are widespread in the United States. However, their activity as measured by their destructiveness to pole timbers varies considerably throughout the country and within any given area. Thus, in northern California there are many miles of pole line showing no evidence of ever having been infested, although generally speaking the area would be classified as one in which subterranean termites occur. The indications are that activity is greatest in the warm southern area. The fact that this kind of termite enters the poles from below the ground line has an important bearing on the methods of prevention and control recommended in this report.

Dry-wood termites, as shown by the map in figure 59*b*, have a much more restricted range than have subterranean termites. Further, their performance is not the same in all areas in which they occur. In some cases they work near or below the ground line and in others, entirely above the ground line. This performance, of course, has a direct bearing on methods for prevention and control.

There are various theories to explain why dry-wood termites infest one portion of a pole in one case and another portion in another case. Some of the factors believed to have a bearing on the matter are temperature, humidity, and availability of natural wood. Temperature and humidity are involved both as to degree and range. Thus, it has been observed that on warm ocean fronts, *Kalotermes minor,* the common dry-wood termite, carries on destructive activities throughout the length of the infested pole from the ground line to the top, and also works in crossarms. The other extreme will be found in the desert or semi-desert areas of low humidity, having hot summers and cold winters, where the dry-wood termites confine their operations to the portion of the pole near or entirely below the ground line.

Intermediate between these conditions there are still other areas where the activity seems to be confined to a portion of the pole extending several feet above the ground. Finally, there are areas which would be classified with those in which dry-wood termites occur, but where there are fewer cases of infestation and the destructiveness is not very great. The inner part of the Mohave Desert is typical of this condition. How these characteristics of the dry-wood termite affect the problem of prevention and control will be discussed in another section.

An interesting observation that is frequently made by persons familiar with the current condition of pole lines is that often infestation is discontinuous. Insects may have been recorded at one inspection as present or as having left definite signs of structural damage, yet examination at the following inspection would perhaps disclose no signs of their presence or of their having in the interim caused any structural damage (Appendix A).

To briefly state the present view of the termite situation in California as related to pole lines, therefore, it may be said that the exposure to damage below ground is fairly general, but exposure to top damage is limited, with the exceptions noted above, to the warm ocean fronts. It also appears that there are intermediate classifications between top attack and butt attack that can be made. It has not been shown that the warm ocean fronts of California differ from those in the rest of the country in exposure to decay or termite attack, but the use of pressure treated southern pine for both poles and crossarms on the basis of availability has probably served to divert attention from these matters in other states.

In response to a circular sent out by the Termite Investigations Committee, replies were received from nineteen utilities operating pole lines in California and western Oregon and Washington. The following questions, which were included, were intended to disclose what service record information was available on termite distribution and destructiveness.

> Number of poles in company's system. What percentage of poles are believed to be infested?
>
> In what year was termite infestation first noted on your properties, and what species, and where found (damp-wood, sound-wood, or subterranean termites)?
>
> Types of structures attacked (buildings, poles, derricks, fences, etc.), kind of wood (fir, cedar, redwood, etc.), and location of attack (butt of poles, sills, floors, studs, etc.)?
>
> Age of material when infestation was first noted?
>
> Amount of replacement necessary as a result of termite attacks?
>
> Estimated monetary value of total damage annually attributed to termite damage, and to damage caused by dry rot (poles, buildings, etc.)?

It is difficult to circumscribe the questions in a circular of this kind so that definite categorical answers may be given. For this reason respondents are prone to qualify their replies and a composite of the answers to a particular question cannot readily be made, or replies may be misinterpreted. In reviewing the replies and preparing the statement of results which follows, allowance has been made for these difficulties.

The replies showed that respondents operated pole line plant aggregating some 3,397,000 poles, but they had very little information regarding the percentage of their poles infested with termites. Only one company gave an unqualified answer (15 per cent) to this part of the question. Two companies made no reply, while three either said the infestation was small, more or less, or not serious. Four companies estimated or thought that a given percentage of certain poles, such as the untreated ones, those in severe exposure, or those in certain lines, were infested, but did not give the number or portion such poles were of the total. Six companies furnished percentages which they stated were either estimates, approximate, fair guesses, or unreliable. Six companies frankly stated that they either did not know, could not say, had no basis, kept no record, or that it was not practicable to maintain a record.

The above mentioned percentages taken at their face value and weighted for the number of poles in the plant operated by the respondents (about 2,810,000 in all) indicate that about 20 per cent of these poles are believed to be infested. Determined separately, the percentage in southern California was nearly a third as large again as for northern California, but the number of poles believed to be infested was more than a third greater for northern California.

Only two companies reported knowledge of termite infestation prior to 1911. One reported that infestation was first noted around Seattle in 1898, and the other that observation of termite damage to bridge structures was recorded in 1904. In neither case was it definitely stated that pole lines were involved. The first infestation of poles noted was in 1912 for subterranean termites, 1913 for damp-wood termites, and 1916 for dry-wood termites. Few companies reported recognition of more than one kind of termite infestation in poles prior to 1920, and only six have so far recognized all three types. The dates of recognition are scattered from 1920 to 1930. The subterranean termite was the most frequently reported, with the dry-wood and damp-wood coming next in order. Only one company among those operating exclusively in the South reported damp-wood termites, which they found principally in mountain regions. Only four companies among those operating exclusively in the North reported dry-wood termites. None of the kinds of wood ordinarily used for pole line construction appears to be immune from attack, since infestation was reported for cedar, redwood, Oregon pine, and pine. It is probably unnecessary to say that this question and the answers relate to untreated wood. There was no difference in the number of companies reporting top (above ground) attack as between the North and the South, but there was a greater number in both areas that reported butt attack.

In regard to the age of the poles when infestation was first noted in them, only nine out of the nineteen companies reporting were able to furnish definite information. Many stated that they did not know. Seven companies gave both minimum and maximum ages varying from two months to eight years, on the one end, to thirty years on the other. Three companies gave a single age of ten, seventeen, and eighteen years, respectively.

Of the definite replies received to the question regarding number of poles replaced on account of termite attack, seven companies stated they had no information, seven others had never removed poles on account of termites, and the balance made indefinite replies. Of the latter, two said they had "very little" replacements for this reason, one could not distinguish between "decay" and termites, one did not distinguish between poles and other plant, and one discussed indefinite portions of its pole line plant.

Ten companies were unable to furnish information regarding monetary value of damage to poles due to dry rot and to termites. Five companies definitely stated they had never replaced poles on account of termites. Most of the latter made no mention of dry rot. Four companies made an effort to express monetary values. One of them, operating a relatively small plant of 47,750 poles, estimated $1,122 per month for termites, but in reply to the previous question this respondent said decay and termite attack could not be separated. Two other companies gave figures, but poles were not listed in the items of plant mentioned in the previous question and apparently they had no pole expense recognized as due to the causes mentioned. Only one company endeavored to expreses its estimate of the expense due to dry rot and termites separately. In a supplemental report one company estimated $13,000, or $1.83 per mile of line, chargeable to termite destruction. This estimate was arrived at by taking 40 per cent of their entire replacement expense. Repair expense was not included.

PRESENT VIEW OF PREVENTION AND REPAIR OF TERMITE DAMAGE

Figure 169 and tables 59 and 60, previously discussed, express very plainly the view of the pole-using utilities, as recently as 1929, with regard to the preservative treatment of pole line timber. It was seen that very little preservative material, other than creosote, was being employed.

In this connection it will be of interest to present the results obtained through the Termite Investigations Committee's circular, in which were included three questions relating to this phase of the subject, as follows:

> What steps have you taken to combat termites?
>
> What is your opinion regarding the success or failure of the various treatments with which you have had experience?
>
> What do your records show regarding the life of treated wood as compared to untreated wood (for all types of structures, poles, etc.)?

The returns indicated that only one company was committed to a regular policy of using full-length pressure creosoted poles generally. In this case both Douglas fir and cedar were being so treated. Two other companies, while using full-length treatment generally, were not entirely on a pressure basis, but were using pressure treatment for southern pine and open-tank full-length hot treatment for western cedar. Eight companies were regularly using open-tank butt treatment with creosote, and five of these also used full-length pressure treatment to some extent. Two companies used butt treatment with creosote sometimes. Brush treatment for new poles did not appear to give satisfaction and has been generally abandoned for more effective methods. It will be recalled that the 1911 view was that superficial brushing, thoroughly done, had proved temporarily efficient in keeping out wood-boring insects. Experiments with other preservatives, including both pole and ground treatments, were reported by one or two companies, but these had either been judged ineffective or were as yet indeterminate. The various ground treatments, which included such materials as lime mortar, asphaltum, and salts of substances like arsenic, copper, etc., were not reported to be very satisfactory, and some were believed to have increased the rate of decay through retention of moisture and for other reasons.

A number of companies definitely stated that they had experimented with preservatives on partly decayed or infested poles while these were still in service, using such remedies as creosote; compounds of arsenic, including Paris green, sodium arsenite, and "bag house" dust; crude petroleum and its derivatives. However, it was not always clear whether pole or other wooden structures had been treated, particularly with reference to sodium arsenite. Again, with possibly one exception, the crude oil and derivatives were used only by their producers. In general, it appears that there is little enthusiasm regarding the effectiveness of preservatives applied to poles in service. However, a few reserved their final decision with respect to one or two of the treatments until further time had elapsed.

Practically nothing was mentioned regarding recovered poles or their re-use.

Only four companies gave figures for the life of both treated and untreated poles. Some had no records or no experience, and most companies stated that treated poles had not been in use long enough to establish ultimate life figures. Most of the replies given were stated to be based on opinions rather than records, particularly as regards treated poles. It appeared from the context that some respondents had service-life in mind while others were doubtless reporting their opinion of physical life. The data given were as in Table 61.

TABLE 61

Reply No.	Untreated	Treated
1		Open-tank creosote: 5 years per ¼-inch penetration
2		Full-length: 10 years
3	Cedar: 4 to 25 years (average 12 to 15 years)	Open-tank: only 12 years' experience, but believe 20 years
4	Cedar: 17 years	Cedar, open-tank: 30 years; fir and pine, full-length: 40 years
5		Brush: 16 years; open-tank: 20 to 25 years
6	12 to 16 years	Butt treated: 25 to 30 years
7		Double life of untreated
8		Double life of untreated
9		50 per cent greater than untreated
10	10 years	
11		Creosote effective 15 to 20 years
12	Fir: 5 years	Fir, pressure: 30 to 50 years
	Redwood: 20 to 40 years	Fir, butt: 10 to 20 years
	Cedar: 10 to 20 years	Cedar, butt: 20 to 30 years

Since the question of pole life has claimed so much attention, it will be of interest to recapitulate the figures previously quoted in our historical review.

TABLE 62

	Average life in years	
	Untreated	Open-tank butt creosoted
N.E.L.A. committee estimate of 1910, based on reports from 165 companies	13½	....
P.C.E.A. committee of 1926, based on report of inspection of 7 California companies	10 to 15	15 to 20
P.C.E.A. committee of 1927, report of California Railroad Commission and Pacific Gas and Electric Company	19	27
Report of California Railroad Commission and Southern Sierras Power Company	17	28
Southern California Edison Company, Ltd. Valuation Dept., based on fairly complete historical data	17	....
Based on several "best" estimates	....	25

Enough has been said with respect to pole life to establish the point that this concept has its principal significance when related to the utility or lines from which the statistical data are derived. Transferred from there, it must be used with considerable regard for the history of its origin. It would appear that, for common usage, it would be better to ascertain, if possible, the average rate of decay for untreated poles, generally best expressed in terms of annual loss of equivalent circumference at point of stress. This measurement, together with the period of effectiveness of whatever treatment is applied, provides a basis which may be used by any utility for any line, in designing for a given physical life objective.

That there is considerable variation in rate of decay with kind of wood and location will be seen by reference to test data presented herein. For example

(Appendix A), untreated chestnut poles installed between Omaha and Denver lost an average of 1.21 inches of circumference per year for the sixteen years under observation, while two lots of untreated chestnut poles installed between Buffalo and Warren, one lot green and the other seasoned, lost an average of 0.26 and 0.38 inches per year, respectively, for the twenty years under observation. It will be observed that seasoning before installation did not yield any advantage for poles installed without receiving preservative treatment. Since western red cedar is the principal timber open-tank butt treated for use in California, it should be pointed out that although the Los Angeles test lines lost 1.02 inches per year up to the time 40 per cent of the poles had been removed, it does not follow that this rate applies throughout the state. For routine design work in the northern area, the principal telephone group uses 0.45 to 0.5 inches. However, any company having a line to design for a given locality using any of the common pole timbers can determine the rate for that locality from measurements made on existing lines.

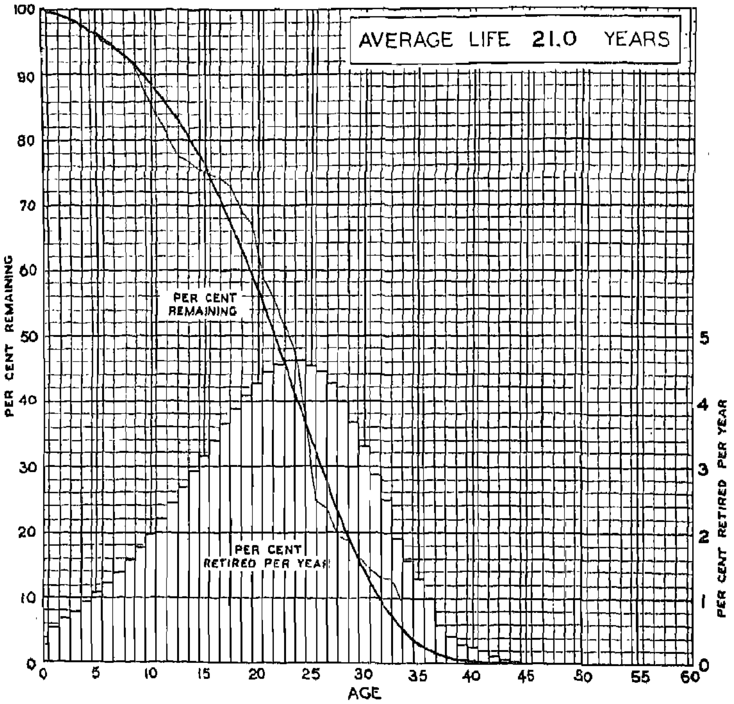


Fig. 170. Curve illustrating mathematical statistical method of determining average life of plant where there is a substantial variation of age of retirement.

While open-tank butt treatment has not been practiced long enough to permit final results to be stated, and experimental lines have not yet reached complete replacements, there is enough evidence at hand to form the basis for quite dependable estimates of period of effectiveness for butt treatment.

Recently there has been considerable publicity given to the mathematical statistical method of determining average life of plant where there is a substantial variation in age of retirement. Extended application of these methods to thousands of plant life tables has demonstrated their suitability. A set of constants can be determined from which a curve may be derived representative of the retirement experience of the class of property, and it will provide a scientific basis for projecting observed life out to its close (Bibliog. 86, 84, 95, and 98). Figure 170 typifies such a curve prepared for a certain group of poles.

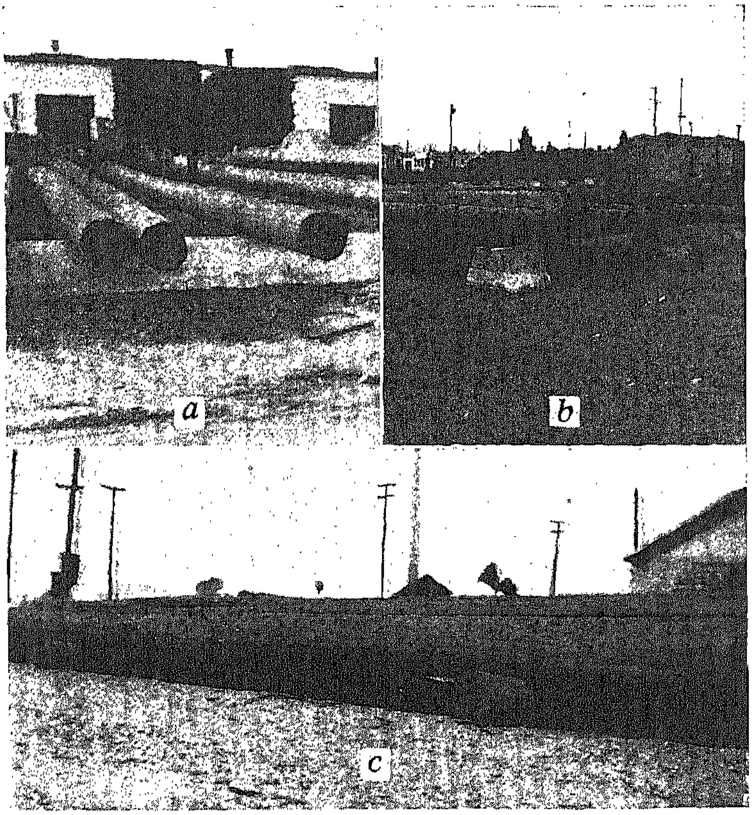


Fig. 171. Types of foundations for poles stored in yards in California. *a*. Continuous concrete. *b*. Steel rail on concrete piers. *c*. Creosoted poles.

In this case the poles were mostly untreated and their average service life was 21 years, as determined by the retirement experience analyzed for a particular group of years. All such curves are characterized by relatively low initial and final slope, with various values of intermediate slope. In the Los Angeles tests of butt treated cedar it was seen that 75 per cent of the poles were sound after 16 years' service. If we consider each specimen as a unit of treatment and extend this data by the most probable curve for this class of plant, an average period of effectiveness of 20 years is obtained for these treatments. Therefore, to obtain a physical life of 30 years would only require four or five inches of wood in addition to the minimum replacement circumference required for structural purposes.

Sufficient evidence has been adduced to encourage an expectation of some 35 or 40 years' physical life for full-length pressure treated pine poles and, as has been shown, some respondent companies are anticipating about the same performance for full-length pressure treated Douglas fir, although there is not the same experience behind the two. It would probably be conservative to expect about the same physical life for full-length pressure treated fir and butt treated cedar in areas where the latter has been found to be satisfactory.

Prevention of decay begins in the pole yard. Poles should be kept off the ground or separated therefrom by treated timber, metal, or concrete. Figure 171 illustrates typical pole yards in California.

Many a treated pole has been ruined by the use of sharp tools which destroy the preservative envelope. Safeguards in this respect are particularly desirable with timber having little sapwod and consequently low penetration of preservative.

When untreated poles have been in service only a short time, some means of arresting decay at the butt might prove attractive, providing it was cheap and effective and could be applied when the butt was exposed for inspection, thus saving this part of the cost. Various means have been tried, including brushing and spraying with hot creosote, flooding with oil, surrounding with dust, granules, or paste of arsenic compounds, etc. (Bibliog. 100). Most of such remedies have not proved very effective, and some are too costly except where they constitute a by-product otherwise used in the business. Where a short extension of life is all that is required and decay and insect activity are not severe, some use is made of such measures.

When poles have reached or are near their replacement condition, stubbing and resetting are usually practiced where conditions are suitable. Stubbing consists in cutting off the old butt and placing a new one, which may be treated, against the old pole top. Resetting consists in cutting off the old butt, pulling it out, cleaning out the old hole, and dropping the top back in place. Obviously, this can be practiced only to a limited extent on account of loss of pole height.

When the tops of old poles are affected, it has not been found desirable to apply other remedies than replacement. In cases where dry-wood termites have done a limited amount of destructive work, the insects may be eradicated by the use of arsenic dusts, but the permanence of such treatment has not yet been determined.

Infested poles removed from the line are destroyed if unsound. Arrangements for burning are sometimes made with municipal incinerator plants, or company-owned incinerators are employed. Sound poles or sound pole tops are recovered and re-used if cost and other conditions warrant. Some companies having local treating plants have introduced the practice of treating such recovered poles. Both open-tank full-length treatment and pressure treatment full-length are used in such cases by a few companies. Where drywood termites are not involved there are, of course, many good butt treated poles removed after short service, the tops and butts of which are perfectly sound, and which may be readily used again, particularly in city work. Figure 172 illustrates a typical incinerator and a treating plant in California.

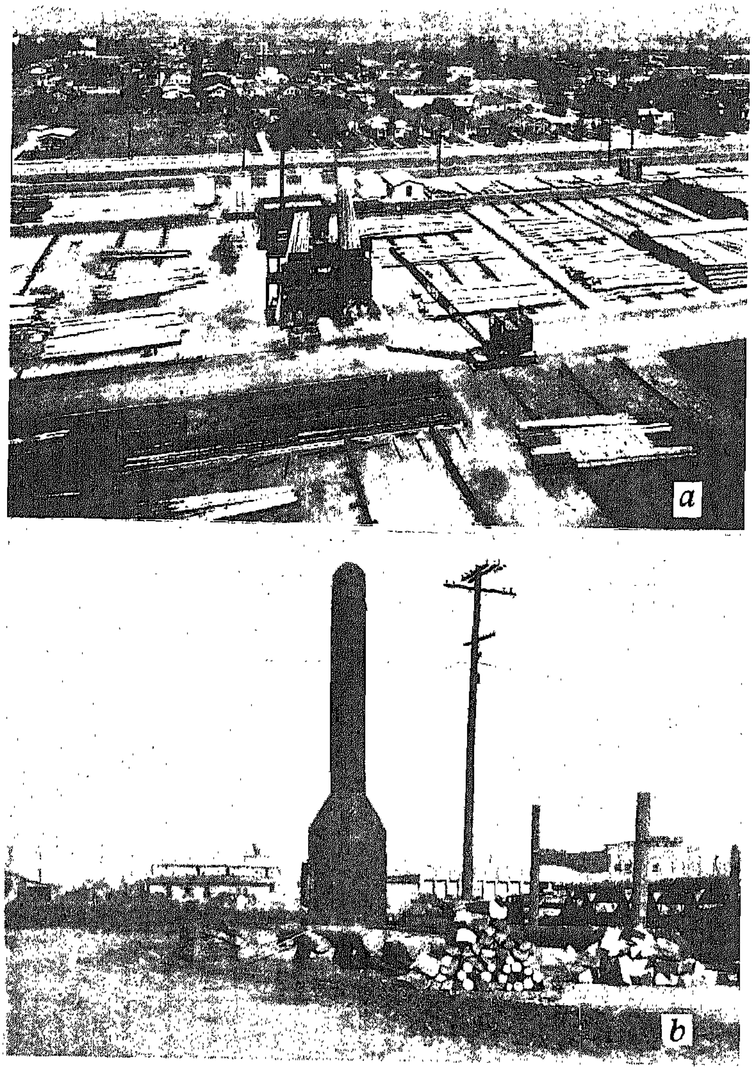


Fig. 172. *a.* Air view of a pole-treating plant in California. *b.* Incinerator at a pole yard in California.

CONCLUSIONS AND RECOMMENDATIONS

The work of the Termite Investigations Committee has confirmed the conclusions previously reached by the larger pole users based upon investigations extending over more than thirty years.

Insects, including termites, have been recognized as belonging to the group of destructive agencies, but it was not found practicable or necessary to separate the termite question from the general decay problem, which is by far the more serious from a structural standpoint except, perhaps, in special cases.

The possibility of extending the life of poles through preservative treatment has been abundantly demonstrated, but the full potentialities of the more effective processes of treatment can as yet only be estimated. It has been demonstrated that thirty to thirty-five years is a conservative estimate for the physical life that may be obtained by using southern yellow pine poles pressure treated full-length with creosote. The physical life reflects, of course, any initial provision of sound wood more than the minimum required at the end of the service-life. Since pine is not very durable in contact with the ground, the period of effectiveness of the treatment will probably be only slightly less than the physical life. Further, through improved uniformity in the product, it has been found that it is possible to obtain satisfactory life with the empty-cell process, which has recently been more generally adopted for full-length pressure treatments. It has also been shown that a period of effectiveness of twenty years for open-tank creosote treatment is a conservative estimate, so that provision of very little wood beyond the minimum requirement makes a thirty-year physical life obtainable. It will be understood, of course, that these ages will not be realized where the poles are removed from service before the end of the physical life is reached. Where service-life is considerably shortened by causes other than decay, it appears that a physical life consistent therewith may be obtained through the use of creosote mixtures employing petroleum as a diluent when treating wood that will not be placed directly in contact with the soil.

As indicated previously, there are places, such as within the Mohave Desert, where preservative treatment would not seem to be required because of termite activity.

With few exceptions, open-tank butt treated poles are now and have for some time (probably ten years on the average) been in use in all areas in California where such treatment is indicated by the investigations of this Committee (see figure 44 and discussion herein under the heading of "Present View of Distribution and Destructiveness of Termites"). Since it has been shown that subterranean termites enter the poles from below ground level it is believed that proper butt treatment provides the best means for repelling attack by this kind of termite. Also, it has been shown that the dry-wood termite under some conditions confines its operations to the portion of the pole near or below the ground, so butt treatment would be sufficient in these cases as well. In these locations untreated Douglas fir crossarms are entirely satisfactory.

It appears that there are certain locations in California where the character of the destructive work done by the dry-wood termite is such as to make the use of full-length treated poles and treated crossarms desirable if freedom from infestation is required from a structural or other standpoint. However, it has not been demonstrated that sufficient structural damage has occurred to justify this procedure in all cases in such areas. And on the other hand, full-length treatment of poles as a pest control measure would not be very effective unless all wood users, including householders, were to practice equally effective measures, and that would require statutory enactment. Southern pine poles, pressure treated full-length with creosote, have long been used in other states where decay and termite activity are probably as serious as in any part of California. Such poles have proved entirely satisfactory and the indications are that other timbers, such as Douglas fir, may be used under similar conditions.

About ten years ago the termite situation in southern California was canvassed and the distinctions between butt and top attack sharply drawn. It now appears that there are locations where full-length treatment would not be justified because of termite activity, but where the usual butt treatment would not reach high enough. Whether to introduce a third style of treatment (high butt) or throw these cases in with the other classes, is a problem for the utilities to determine on the basis of frequency of occurrence, cost, supply conditions, and other practical considerations.

Such ground treatments as have been tried have not been reported to be very satisfactory, and relatively few experiments with this method of prevention in connection with new pole lines are being continued.

Experience has shown that the application of preservatives to the butts of poles that were untreated when placed and which are already well on the road to decay is not a satisfactory proceeding. After trial most companies have abandoned these practices. Of course, in special cases, as with companies operating a small pole plant incidental to the manufacture of a preservative, and having special research facilities available, there would be good justification for a different viewpoint. The application of preservatives to the tops of poles already in service has not been practiced or suggested for retardation of decay. It would only be of interest in connection with dry-wood termite infestation. Various arsenic compounds have been suggested from time to time and arsenic dust has been tried in the Hawaiian Islands and more recently in southern California. Specimen poles, on dissection, have revealed a complete kill, but insufficient experience has been had to determine the uniformity of the results to be expected on extended application, or the degree of freedom from reinfestation.

In connection with the application of preservatives to poles already in place, it should be pointed out that proper facilities and supervision cannot be readily made available in the field, since many pole lines are hard to reach, and there are attendant hazards with fires in dry seasons, when the work should be done, and with poisons at any time.

The re-use of old poles recovered from plant can only be practiced within limits determined by the amount of transporting and handling required. In cities and towns, sound poles, particularly treated poles, can readily be re-used. Treating or retreating after removal of unsound portions is, of course, the same problem as for a new pole except for the provision of facilities. Only one or two companies have installed their own treating plants, so the practice of treating recovered poles is not general. Some companies do not consider their experience in treating recovered poles to be satisfactory, particularly where few of their salvaged poles are fit for treatment.

Upon removal from service, unsound poles or infested portions of otherwise sound poles are destroyed by burning. Generally speaking, all unsound timber is destroyed in this manner. Some companies have their own plants for this purpose and others have arrangements with municipal incinerators. Where it is necessary to haul too far to reach an incinerator, the infested material is burned in the open or, when not infested, it is sold or given away for firewood. Where open fires are not practicable, the Committee recommends that infested poles or butts be split open so as to expose the termite galleries to the light.

In storing and handling poles, regard should be had for the importance of providing suitable instructions and means so that as far as possible treated poles will not be damaged by sharp tools. Untreated timber should not be stored in contact with the soil, and the practice of orderliness, segregation of decayed material, cleaning up of débris, etc., are of the same importance in a pole yard as they are in the yards of private residences and other places where wood materials are used.

Considerable progress has been made in developing methods of inspecting and recording the condition of pole lines. If it should prove to be desirable, the larger pole users could, doubtless, easily record on their routine forms the presence of termites and termite destruction, provided that simple means of detection can be developed. This seems to be the principal obstacle in the way at present. Apparently, in climates with wide range of temperature, colonies change their level of operations during the seasons, so that, unless the structure as a whole is investigated, it is exceedingly difficult to make certain about the presence of termites or damage caused by them. Most descriptions of termites and their work, so far provided, are too technical to appeal to the workman. On account of extreme magnification employed in photographing and illustrating termites, and the use of black and white instead of natural colors, it requires imagination to visualize the real insect therefrom. It is not practicable to offer much biological training to these men. Another factor to be considered in this connection is that poles cannot be completely exposed below ground while in service, so no one can definitely state on the basis of the usual inspection what infestation, if any, exists.

APPENDIX A TO CHAPTER 49

RESULTS FROM THE PRESERVATIVE TREATMENT OF TELEPHONE POLES

(An unpublished report of the American Telephone and Telegraph Company dated August 3, 1931.)

For a number of years the Bell System has been observing the performance of preservative treatments of coal-tar and wood-tar distillates as applied to wooden poles in service. The results of these observations up to the year 1915 have been presented in a previous paper (1). Since then there have been several publications (2) bearing upon the performance of some of the series of poles covered in this first paper but nothing has been prepared covering all of the poles. It is the purpose of this report to assemble the data obtained from the inspection of the experimental groups. No attempt is made to draw final conclusions as to the performance to be expected from the various preservatives or methods of preservation under observation.

At the time the experimental installations began, pole practice in this country was based upon the use of several species of timber possessing high specific resistance to decay when exposed in contact with the soil. This characteristic has made practicable and economical the use in an untreated condition of poles drawn from these species. These timbers further possessed the desirable characteristic of substantial freedom from decay when exposed above ground and consequently the period of serviceability for poles of these species was determined almost entirely by decay in the part embedded in the soil. One of the objectives sought in the work to be described was the development of "butt treatments," which would increase the period of serviceability for those species of timber at that time commonly employed.

There are sections of this country where the locally available species of timber possess all other desirable characteristics of a pole timber but are subject to decay even in the parts exposed above the soil. To make poles derived from these species available it is consequently necessary to apply a preservative treatment to the entire surface of the pole, or in other words, to apply a "whole-length treatment." It is true that the risk of decay attack is not uniform for all parts of the pole under the conditions of service exposure, but the difference is one of degree only and does not eliminate the desirability of preservative protection for any part of a pole derived from a species of timber not naturally decay-resistant. While this class of treatment has up to the present time been applied extensively only to the group of timber species commonly classed under the name of southern yellow pine, there are a number of other species of timber available in substantial quantities which may in the future come into extensive use for poles through the employment of whole-length treatments.

WHOLE-LENGTH TREATMENTS

The experience with whole-length treatments to be described covers service exposures of southern pine poles treated with creosote and installed in two lines of the American Telephone and Telegraph Company. The first group of poles to be installed was located in Virginia and formed most of the Washington-Norfolk line. The other group located in Alabama, Mississippi, and Louisiana formed a substantial part of the Montgomery-New Orleans line.

Washington-Norfolk Line.—This line extends from Washington, D. C., to Norfolk, Virginia, and was built during the summer and early fall of 1897. For some 20 miles south of Washington, chestnut poles were used in its construction. For the remaining 225 miles creosoted pine poles, numbering a little over 9,900, were employed. Of these approximately 400 were of circular cross section, and the remainder were sawn to specified dimensions.

The sawn poles were principally of a square cross section, only 13 having an octagonal cross section. The sawing was specified to be done at a taper substantially greater than the natural taper of the tree trunk so as to result in the removal of all sapwood from the upper 6/10 of the pole. To meet this requirement, the sawn poles had to be secured through the cutting of old growth longleaf pine trees. The sapwood remaining on the corners of the lower 4/10 of the pole measured, on the average, a little more than an inch on a side at the ground level. The circular pine poles, on the other hand, appear to have been secured mainly through the cutting of shortleaf or loblolly pine and on the average a large proportion of their cross section consisted of sapwood.

All of the pine poles were specified to be impregnated by the pressure process with not less than 12 pounds of creosote per cubic foot of wood. The poles were prepared for this treatment through preliminary steaming followed by vacuum. The steaming specifications called for the use of both superheated and saturated steam.

In December, 1914, to carry out a plan for determining systematically the performance of the creosoted poles in this line, a thorough and detailed inspection of 1,523 sawn poles and 122 circular poles was made. The poles inspected were grouped in nine test sections located at intervals along the creosoted portion of the line. Removals of creosoted poles for decay prior to December, 1914, when the test sections were established and first inspected, amounted to 26 in the test sections out of a total of 40 recorded for all of the creosoted part of the line.

In the six years following 1914, line changes led to the removal, from their original service in the test sections for causes not connected with damage by decay, of 330 sawn poles and 32 circular poles. However, since many of the sawn poles removed from the line were of lengths frequently in demand, opportunities arose within a year for their re-use in two lines running south and west from Petersburg, Virginia, and 198 of these poles were located and their records have been continued in the test data.

The second inspection of the test sections was completed in the year 1923. Table 63 gives in summary form the results of the two inspections of the test sections. Results are shown separately for sawn specimens and for circular specimens.

Decay attack was usually found to begin at centers of narrowly limited surface areas. It has consequently been practicable to divide and classify the cases of decay attack with respect to their position along the length of the poles and the results of such classification are given in Table 64.

In this classification ground section attack covers decay located at least in part below the ground line and extending not more than two feet above it. Top section attack covers decay starting in the top surface of the pole. In the case of the sawn poles the top was square cut and therefore approximately level, and in the case of the circular poles was double cut to provide a roof with an angle of 90 degrees between the cuts. Side section attack covers all decay occurring in the sides of the pole and not included in top or ground section classifications.

In both sawn and circular specimens decay starting in the ground section is shown to be the principal form of attack. In sawn specimens almost all of the decay attack not located in the ground section occurs in the top section. However, slightly more than half of the top section attack on sawn specimens occurred on poles whose tops had been cut back after treatment, resulting in the exposure of a central untreated core, so that the normal proportion of attacks in the top sections would not be so great as is indicated by the figures of the table. Side section attack is a rare occurrence on the sawn specimens but the number of centers of attack on the circular specimens is substantially the same as that of top section attack. Most of the side section attack, however, has been traced to shallow penetration, whereas this cause has only infrequently been found associated with top section decay.

Classifications of the decay attacks by type or cause are given in Table 65. On about three-quarters of the damaged poles, decay attack upon both sawn and circular specimens started at the outside surface and proceeded inward. With sawn specimens most of the attack which started below the surface was covered by a shell of less than one-half inch in thickness and was usually due to the opening up of access to untreated wood by checks located near the center of one or more of the sides. Internal attack on the circular specimens, however, usually occurred at considerable depths below the surface (one inch or more). More than half of the decay attacks on the tops of sawn poles occurred on specimens whose tops, after treating, had been cut back for line grading. About three-quarters of these cases of decay at cutoff tops were found to have started before the first inspection, but in nearly one-quarter of the cases decay did not begin until after that inspection. There were 30 specimens of a total of 72 poles whose tops had been cut off which had not shown any starting of decay up to the time of the second inspection. Usually, decay at the cutoff tops was found to have proceeded slowly, probably because of the relatively high resistance of longleaf pine heartwood to decay. Up to the end of the second inspection, only two poles, where decay had started at cutoff tops, were found to be sufficiently damaged to call for the removal of the pole. Slightly less than half of the cases of top decay on sawn poles occurred on specimens whose tops had not been cut off. Most of these decay attacks were slight in respect to the amount of damage occurring up to the second inspection.

In the case of poles which developed decay, it was usually found that the depth of penetration in the heartwood was shallow. In many such cases the penetration recorded was from ⅛ to 1/16 of an inch and in a few cases it was less than 1/16 of an inch. It is in those cases where penetration is shallow, and the quantity of preservative therefore probably small, that early failure through depletion of the preservative might be expected, as is indicated in Table 65. In the case of the fully impregnated sapwood corners of the poles, instances were not infrequently observed at the second inspection where decay had started as a result of depletion of the preservative.

Other causes of decay attack include shakes, the formation of which is distinctly favored on the sawn specimens by the taper to which they were sawn; splits; pith holes; rotten knots, and scars; and mechanical injury, under which are included tool injury, bruises, and woodpecker holes. None of these appeared as causes of decay in sufficient frequency to compare in seriousness with checks in the side of poles and preservative depletion. In spite of the fact that checks (principally in the ground section) were the second most important cause of decay on sawn specimens, the number of poles with checks causing decay (51) is relatively slight compared with the number of poles with checks recorded appearing upon the poles (459).

Failures to secure proper penetration of the preservative were a fairly frequent cause of decay attack and, together with cases of decay underlying a sound exterior, account for most of the early appearances of decay on circular poles, as recorded in Table 65. Most of the new cases of decay appearing at the second inspection were on the surfaces of the poles in treated wood and appeared due to depletion of preservative in the outer layers.

Top decay on circular poles was principally due to shakes, with checks coming second as a cause. The only circular pole with decay originating in the top sufficiently damaged to lead to its removal had had its top cut off after treatment.

Experience on this line with respect to insect infestation is summarized in Table 66. The ratio of insect infestation to decay occurrence is not high. Termites are the principal kind of insect encountered, with black ants showing up in fair proportion on the sawn poles. Damage has been slight in the case of the sawn poles and not very heavy in the case of the circular poles.

The prevalence of insect infestation, and of structural damage to pole timber resulting therefrom, varies widely with locality. In most cases where structural damage to poles has been caused by insects, it has been found so associated with fungus attack as to make it impracticable to appraise the relative damage caused by each organism. In a relatively few cases where insect damage was not associated with decay, the indications are that the effectiveness of the preservative had been so reduced by duration of exposure that it no longer acted as a deterrent to the insects. In most cases there is evidence which indicates that insect attack occurred following decay or as the result of exposures of untreated wood, either through failure of the wood to receive treatment or through openings in the treated layer.

As a result of a maintenance inspection made in 1927 and 1928, of the poles still in use in the Washington-Norfolk line, 3.3 per cent of the 1,016 experimental sawn specimens in line were designated for reconstruction on account of damage by decay, and 6 per cent for reconstruction to improve clearance. In the case of the experimental circular poles, 12 per cent were found to require reconstruction on account of damage from decay, while none were designated for reconstruction for other causes.

Experience with sawn poles has offered an opportunity to observe the resistance of longleaf heartwood against decay when assisted by a creosote treatment. Even in the case of poles which had had their tops cut back, thereby exposing untreated heartwood, the progress of decay downward was not rapid. Considering the exposure of heartwood at the ground line where conditions are most conducive to encouragement of decay, only one-third of the 123 specimens showing decay on inspection at the end of 17 years were found, approximately 8 years later, to require replacement for this cause. These observations support the conclusion of substantial resistance to decay as a normal characteristic of heartwood of this species. There were individual cases, both before and after 1914, of rapid deterioration of the sawn specimens, which suggest that this characteristic of resistance is not an attribute of all individual specimens of longleaf pine. These cases of quick failure are not, however, numerous.

Montgomery-New Orleans Line.—This line, built in the summer and fall of 1899, used creosoted circular pine poles in the 160-mile stretch from Hurricane, Alabama, to New Orleans, Louisiana. Owing to the large proportion of H and tripod fixtures and poles braced in four directions necessitated by the swampy nature of the terrain traversed, the number of creosoted poles, stubs, and braces installed amounted to approximately 7,650.

The poles were specified to be of longleaf yellow pine, the majority being 20 or 25 feet in length, although some braces only 15 feet long were employed. Most of the timber which has been examined is narrow ringed material of considerable age with only moderate sapwood thickness. However, there has also been found an appreciable percentage of poles derived from either second growth longleaf, slash or loblolly pine growing under old field conditions, showing relatively wide rings and containing little or no heartwood. Impregnation of creosote in the latter material usually spread over most of the cross section, whereas in the former timber the treatment averaged somewhere between one and two inches in depth.

All pine poles were specified to be impregnated by the pressure process with not less than 12 pounds of creosote per cubic foot of wood. For poles intended to be set in salt or brackish water this quantity was increased to 15 pounds per cubic foot. The poles were required to be prepared for treatment by preliminary steaming, followed with vacuum. The steaming specifications called for the use of both superheated and saturated steam.

In January, 1915, nine test sections, chosen to represent the conditions of exposure varying from the swamp settings near Mobile and New Orleans to the inland conditions on the higher ground between Mobile and Pascagoula, were established. These nine test sections contained originally 1,602 creosoted pine poles, stubs, and braces. Records of the line show that a total of twenty-seven poles had been removed from the test section prior to 1915 and that nine of these removals had been on account of deterioration due to decay.

In the fall of 1915, shortly after completion of the first inspection, this territory was swept by a hurricane which resulted in the loss of 133 consecutive poles from one of the test sections, 119 of which were sound. The second inspection was made in 1921 shortly after the first major maintenance replacement of 1919. The third inspection was made in the winter of 1926–1927 and at about the same time as the second major maintenance replacement of 1925–1927 which removed practically all of the original poles from the two swamp sections in order to provide the taller poles necessitated by the growth in business.

In Table 67 is shown the number of removals from service in the test sections, and the year of their removal, distinction being made between removals on account of decay and for other causes. The high figures for removals in 1915 are in consequence of the hurricane already referred to, while the high figures of 1919, 1925, 1926, and 1927 represent the major maintenance replacement operations previously mentioned. The 1,602 specimens placed in the test section in 1899 had yielded, up to the year 1927, an average of 25.2 years in service, with 802 specimens still in line for further service.

In Table 68 are summarized the data gathered relating to the location of initial decay attacks on original specimens in the test sections. It may be noticed that, although decay is most frequently encountered in the ground section, the ratio of the number of decay attacks in the ground section to the total number of decay attacks is lower for the Montgomery-New Orleans line than for the Washington-Norfolk line. This lower ratio is in part due to conditions prevailing in the two swamp sections, which contain a little more than 25 per cent of the test specimens. In these swamps the pole line right-of-way is covered for part of nearly every year with water to depths ranging up to three feet and the proportion of ground section decay recorded there has been very low as compared with the other test sections. The proportion of top section attacks at the first inspection is lower in the case of this line than in the case of the Washington-Norfolk line but is showing an appreciable increase in the second and third inspections as compared with the first inspection.

In the case of a considerable number of decaying specimens additional decay was found starting, at the second or third inspection, in those sections of the pole which had been free from decay in previous inspections. This secondary decay attack occurred much more frequently in the top section of poles than in either of the other two sections. The later inspections have also shown that in about 20 per cent of the decay pockets found in 1915 and 1921 there has been no increase in the cross sectional dimensions of the pocket after six years additional exposure. Usually these pockets extended to a sufficient depth to expose untreated wood, and this recorded experience together with many other cases where decay progressed very slowly in the periods between inspections, supports the conclusion already indicated in the case of the Washington-Norfolk line with respect to the high resistance to decay to be expected from the heartwood of this species of timber.

In Table 69 are assembled data relating to causes of decay. Many of the decay failures noted on the later inspections as check and shake failures in the side section and also in the top section of the poles were found in wood which had apparently received treatment and are probably to be associated with a loss of the preservative quality of the creosote in the walls of these openings. These two groups of failures are consequently closely associated with the preservative depletion group. Checks and shakes were also probably contributory to some extent to those failures noted on the first inspection as caused by shallow penetration.

Decay in the top section was mainly due to causes not affecting the other two sections in any considerable degree. Shakes account for more than half of the top section failures and the check and the center decay classifications account for most of the other failures. The center decay classification covers a type of attack in which a core of substantial diameter, extending downward from the original surface of the pole roof, was removed by decay. By the time this form of damage could be examined by the inspector, the original conditions leading to the starting of the decay had been removed so that a determination of a true cause was not practicable.

Mechanical damage to the treated layer which is expected to protect the interior untreated core of the pole has not as yet appeared as an important cause for the starting of decay. The ratio of attacks due to this classification has, however, been increasing moderately with each new inspection and it may be that as time goes on its importance will become greater.

Table 69 also presents data on the causes of decay attack in relation to the replacements made on account of decay. These data indicate that decay due to shallow penetration has been the principal cause leading to the structural impairment of poles to an extent sufficient to call for their removal from service. It is only in the case of poles removed on account of damage in the top section that other classifications of cause become the major reason for removal from service. Here shakes appear as the principal cause of decay attack. While top decay on the original specimens has occurred in substantial proportions over a long period of exposure, and while shakes are usually the primary cause of this decay, the indications are that such an attack of decay also needs an impairment of preservative efficiency to favor its initiation as well as the assistance towards the collection and retention of moisture necessary for the starting and continuance of fungus growth afforded by the checks or shakes.

Data secured in the inspections of this line with respect to insect and woodpecker attack are set forth in Table 70. Approximately two-thirds of all of the original specimens showing decay have been infested by insects at some time during their period of service. The infestation has in some cases been continuous throughout the period of observation. More often, however, it has been discontinuous, and when insects have been recorded at one inspection as present or as having left definite signs of structural damage, examination at the following inspection would disclose no signs of their presence or of their having in the interim period of exposure caused any structural damage. As in the case of the Washington-Norfolk line, termites of the subterranean type are the form of insect most frequently found. Wood-boring beetles in this line, however, take the second place after termites and appear with substantial frequency as a source of structural damage in many of the test sections. The relation of insect damage to damage by fungi has already been discussed, and it only remains to be added that this line includes practically all of the cases where direct termite attack without simultaneous occurrence of fungus attack was observed, and also the few cases where attack by termites has resulted in a sufficient amount of structural injury to have any substantial influence upon determining the removal of the pole.

Woodpecker attack was almost non-existent in the case of the Washington-Norfolk poles but, as is indicated in Table 70, has occurred in substantial amounts in this line. In localities where poles are heavily attacked by woodpeckers, it has frequently been noticed that the attack is reduced where the line passes through woods and sharply increased in amount where the line passes out of the wooded areas into clear areas.

In all of the recorded cases of the occurrence of woodpecker holes, other than superficial attacks, or nests in poles, the openings extended through the treated shell to underlying decayed timber. It was the experience with woodpecker attack in this line that poles in which there was an underlying region of decay were more frequently selected by the birds for making large holes or nests than were sound pieces, since substantial evidence of trials made by woodpeckers leading to the formation of shallow depressions in the roofs or on the sides near the roof was found on a considerable number of sound poles. Usually the decay opened up by the woodpecker was found to have started from the top of the pole and to be proceeding downward outside of an undecaying core of pine heartwood in an underlying treated layer of the sapwood.

BUTT TREATMENTS

In butt treatments the preservative may be applied by distributing it over the surface of the parts which it is desired to protect, or by immersing in the preservative the part of the pole which is to be treated. In 1905 when the first of the poles were treated there were in existence no commercial facilities for applying butt treatments by immersion. Surface treatments could, however, be applied by construction forces, and for a number of years this was the only readily available form of butt treatment. The surface treatments which were included in the service exposures usually employed heated preservative applied with a brush. Because with a treatment of this kind a ready absorption of preservative does not occur unless the timber is reasonably dry, the poles so treated were first thoroughly seasoned.

Poles butt treated by the open-tank process were also included in the service trials. The poles treated by this process were held with the lower part of the pole immersed in hot preservative for several hours. The hot preservative was then allowed to cool with the poles still immersed. Both seasoned and green poles were treated by this process. The means available for determining the quantity of preservative absorbed by this class of specimens were limited to determining their change in weight during treatment, and as no correction was made for moisture that was lost during the treating period, particularly in the case of the green specimens, their recorded absorption may be somewhat below the actual.

The butt treatment service trials to be described are three in number located respectively in Georgia, in New York and Pennsylvania, and in Nebraska. The first group to be installed was located in the Savannah-Meldrim line of the Southern Bell Telephone and Telegraph Company, the second in the Buffalo-Warren line of the American Telephone and Telegraph Company, and the third in the Omaha-Denver line of the American Telephone and Telegraph Company. The nature of the treatments applied and the performance of the poles treated and exposed in service will be set forth separately for each line.

Savannah-Meldrim Line.—The installation of the poles in this line was completed in the summer of 1905. The location of the test sections is just west of Savannah in a relatively low coastal plain area. The location was known to be one in which untreated poles decayed rapidly.

The pole timbers employed in this exposure were juniper (*Chamaecyparis thyoides*) and chestnut (*Castanea dentata*). Approximately three-quarters of the poles of each of these species were cut in uniform quantities monthly during a period of one year and then held over a considerable period for a study of seasoning. Approximately two-thirds of the seasoned poles were given a brush treatment with preservative, eight different preservatives being employed. The green poles included in the exposure were cut at about the time the seasoned poles were to be shipped for installing in the line.

This experimental installation has been inspected at intervals averaging slightly less than two years, up to the fall of 1921, when the almost complete removal of the juniper part of the experimental group and the general exhaustion of the effectiveness of treatments led to the discontinuance of inspections at the regular intervals. The results of the inspections made are assembled in Table 71 and Table 72. The average decrease in circumference per year, shown in Table 72, is secured by dividing the total observed decrease in circumference by the total number of years in service accrued for the specimens in each lot up to the time of the inspection. The years of service recorded for any individual specimen terminate at removal from its initial setting for any cause. A removal from service on account of damage by decay is recorded as of the year of the inspection at which its necessity was determined.

Insect infestation is shown for each lot, Table 72 giving the total number of specimens infested and also the number of specimens infested by each kind of insect. In most cases the infestations were not continuous from the time when they were first observed.

It will be seen from an inspection of Tables 71 and 72 that later experience definitely establishes the conclusion first advanced tentatively in the former report of 1915 (1) to the effect that seasoning does not lead to an increase in the life of untreated poles. In the case of both the juniper and the chestnut groups of poles experience has been carried to a point which establishes a materially smaller rate of decrease of circumference by decay and, therefore, a distinctly greater average life, for the green untreated poles than for the seasoned untreated poles. The experience also establishes the fact that an increase in life results from the application of preservative. This appears in the postponement of replacement for decay as compared with untreated poles, in retention over the period of several inspections of soundness for a substantial proportion of the treated poles and in a generally lower rate of decrease in circumference by decay for the treated lots. Marked distinctions between the performances of the several kinds of preservative employed do not occur in any consistent way. The most that can be said is that the application of tar appears to be of little value from a preservative standpoint. Insect infestation and attack on the treated poles occur in fully as high proportion as upon the untreated poles but the occurrence of infestation in the case of the former is rendered appreciably more likely by a longer period of exposure in service.

Buffalo-Warren Line.—The experimental poles in this line were installed in 1905 and were located between Gowanda, New York, and Warren, Pennsylvania. This part of the line runs through a rolling country with the hills growing higher and more precipitous as the southern end of the section is approached.

The test poles in this line were all of chestnut (*Castanea dentata*). They were collected at two locations, *viz.*, Dover, New Jersey, and Paoli, Pennsylvania. At both points of collection, lots of test poles were cut at monthly intervals and were first studied for rate of seasoning. After the completion of the seasoning studies about two-thirds of the seasoned poles were treated. Brush treatments were applied using six different preservatives, and open-tank treatments of seasoned poles were made at both supply points, creosote being used as the preservative. At Paoli, while the treatments were being made, green poles were brought in totaling a little over one-third of the seasoned poles collected. Some of these green poles were given an open-tank treatment with creosote, but most of them were shipped to be set in the line untreated.

There have been seven inspections of this experimental series, the latest being completed in the fall of 1929. The results of the inspections are set forth in summary form in Table 73 and 74. As will be seen from the record of poles removed for causes not connected with decay, there have been no changes in this line materially affecting the experimental series. The 1926 inspection of this line was carried out under severe weather conditions and a considerable number of poles could not be reached for examination because of floods.

The retirement of a specimen on account of decay is recorded in the table as having occurred in the year of the inspection which disclosed the removal. Deterioration by decay to a point where replacement has become advisable is covered in the table under a subheading "Condition of Specimens Inspected." The table also gives the number of specimens found sound at each inspection and includes subdivisions giving the decrease in circumference per year and the insect infestation observed.

In 1926 borings to secure measurements of depth of penetration of the preservative were made on the two lots of poles which had received open-tank treatment. Only single borings were made on individual specimens, but the point of boring was carefully chosen so as to be at a place which would have been well immersed in the preservative throughout the treatment. The average depth of penetration observed for 25 specimens treated in the green state was $^{5.1}/_{32}$ inch. The average penetration for 81 specimens treated after seasoning was $^{5.7}/_{32}$ inch. While the depth of penetration obtained in the brush treatments averages distinctly lower, several specimens were bored in 1926 which gave higher figures than these averages for the open-tank poles.

About 65 per cent of each of the two lots of poles treated by the open-tank process were found to be still sound after 24 years of exposure. A substantial majority of the decay failures in each of these lots occurred at points where scars were noticed on the surface, usually at an inspection prior to that at which decay was discovered. There are, however, a number of cases on record where such scars extending through the treated part and exposing untreated wood have not led to the starting of decay for a long time after the condition was first noticed. Approximately 20 per cent of the decay failures of these two lots have occurred at openings through the treated layer resulting from the extension of checks. In recent years a few cases of decay of a superficial nature on the exterior surface have been noticed, probably due to the elimination by long exposure of the decay resisting characteristics of the preservative.

The results set forth in the tables clearly support the conclusion that a greater increase of life can be expected from the employment of the open-tank process than from brush treatments. The performance of the several lots of brush treated poles indicates a substantial gain in life when compared with the performance of untreated poles otherwise similar in history, preparation, and exposure. However, these brush treatments represent applications made with great care upon specimens in exceptionally good condition to receive treatment, and consequently represent a higher standard of performance than can be expected in ordinary commercial practice. The performance represented by the figures in this table should, therefore, be applied with great caution in dealing with any practical use of the process.

This experimental series also includes a service comparison between untreated poles which were well seasoned and others installed green. In the earlier stages of the exposure, the seasoned specimens appeared to be resisting decay a little more successfully than the green specimens but, gradually, the situation has changed so as to lead to the same conclusion as in the case of the

Savannah-Meldrim exposure, *viz.*, that seasoning before installation yields no advantages if the pole is to be placed without receiving a preservative treatment.

Insect infestation data indicate that while this exposure is not to be regarded as severe, experience was sufficient to demonstrate that the preservative treatment can be counted upon to protect against insect damage as well as decay.

Omaha-Denver Line.—The installation of the test sections in this line was made in the summer of 1910. The pole timbers employed in this exposure were chestnut *(Castanea dentata)* and eastern cedar *(Thuja occidentalis).*

The chestnut poles were collected at Parkton, Maryland, and were cut in four lots during the four seasons of the year. The cutting began in the fall of 1905 and the poles were held for a considerable time for studies of seasoning and other characteristics. In the spring of 1907, one-third of the poles received an open-tank treatment, and another third was given a brush treatment, two different preservatives being employed; the remaining third was left untreated.

Eastern cedar poles were cut in lots of about 50 each for nine consecutive months beginning in April, 1905, and were assembled at Escanaba, Michigan, where studies of seasoning and other characteristics were completed in the fall of 1906. Treatment of this group of poles was carried out in November and December, 1906, a small lot of green poles being brought in at that time to receive an open-tank treatment. A little over 40 per cent of the treated poles received an open-tank treatment with creosote; the remainder received a brush treatment, two different preservatives being employed.

Both the Escanaba and the Parkton groups of poles were made available for installation at a time when an opportunity for placing the poles consecutively in line could not easily be found. These two groups of poles were held for over three years before they could be installed, and it was accordingly felt that the long period of holding might have produced changes affecting the performance of the preservative treatments applied. The building of the Omaha-Denver line in 1910 offered an opportunity to use these poles in an experimental installation and, as the plans called for the brush treatment of several thousand eastern cedar poles, arrangements were made to extend the trial to include three additional groups, each group to include about 300 experimental poles of which 200 were brush treated. About 100 poles in each group were brush treated with creosote, which was the preservative employed in treating the poles not included in the test sections. Another third of each group was treated with carbolineum similar in characteristics to that applied to the Escanaba and the Parkton poles, and the remaining third was installed untreated.

The installation of the experimental poles began about 35 miles west of Omaha, near Ashland, Nebraska. The Parkton group was first placed followed by most of the Escanaba group. One group of the cedar poles prepared at the time of placing of the line was located in a branch connecting the main line with the city of Lincoln, Nebraska. Another group was placed just east of Seward, Nebraska, and a third group was located near North Platte, Nebraska, some 200 miles west of the other experimental poles in this line. The country in which these poles are located is relatively level but gradually rising in altitude towards the west.

There have been six inspections made since the experimental series of poles were installed in this line, the last inspection being made in the summer of 1929. The results of the inspections are assembled in Tables 75, 76, and 77. As is brought out in these tables, the removals for causes not related to decay reach a considerable percentage. The principal cause of such removals in the case of the cedars has been breaking of poles by storm; only a few of the chestnut removals were due to storm damage. Removals on account of damage by decay had at the last inspection been substantial in number in all lots of poles except those treated by the open-tank process. In the untreated groups the replacements called for by the 1929 inspection completed the elimination from service of all the original untreated cedar and chestnut specimens. In the brush treated lots, removals from service have also been large. The data presented in the tables indicate that the period of storage for the Parkton and Escanaba groups may have exercised a substantial influence in the way of impairing the resistance to decay of these brush treated poles especially with respect to creosote brush treated poles, and this special condition should be borne in mind when interpreting the results of these tests.

There are three lots of specimens in this line treated by open-tank processes: one of chestnut treated at Parkton and two of cedar treated at Escanaba. Borings have been taken from the treated section of 165 out of the 178 chestnut poles treated by the open-tank process still in line in 1923. The average depth of penetration of preservative found on these borings was $^{5.5}/_{32}$ inch and the average thickness of sapwood was $^{7.2}/_{32}$ inch. Thirty-nine of the 40 green eastern cedar poles remaining in line in 1926 gave an average depth of penetration of $^{12.8}/_{32}$ inch against an average thickness of sapwood of $^{19.4}/_{32}$ inch. Similar measurements on 120 of the seasoned eastern cedar poles gave $^{17}/_{32}$ inch for depth of penetration against an average thickness of sapwood of $^{21}/_{32}$ inch. In the course of the time covered by the tables both the chestnut and green cedar poles of the open-tank group have had an appreciable percentage of poles decay to a condition necessitating replacement. Only a few of the seasoned open-tank treated cedars have shown any signs of the beginning of decay, and on all of these the attack has been on the surface and slight in amount. In the case of the first two groups, the major cause of decay attack was found to be the entrance of decay at checks through the treated layer. Starting of decay at the surface of the treated layer was the principal remaining cause of attack.

Damage by insect attack and woodpecker attack on the experimental poles is shown in Table 77. On the whole, insect attack has become more widely spread among the specimens as the length of exposure has increased. It has not, however, been found occurring prior to any damage due to fungus attack.

LIFE OF POLES

The removals from the untreated lots of poles in the Omaha-Denver and Savannah-Meldrim lines, together with the brush treated juniper poles in this latter line, have reached such high proportions of the total number originally placed that any variation in the life performance of the few remaining specimens for these lots may be disregarded. The service-life performance of these groups of specimens has, therefore, been assembled in Table 78. The data on treated specimens are insufficient, however, to permit drawing any conclusions concerning the relative performance of treated and untreated poles. The data can, however, be used as a basis for computing the relations between the "percentage of poles replaced" and the "percentage of average life elapsed" up to the time of such replacement, and such computations have been made and are set forth in figures 173 and 174 in comparison with the Forest Products Laboratory plots of tie replacements based on records of 127,000 ties, published in 1926. While the data in the table cover experience with only about 1,000 poles, they yield points falling into a fairly definite relation to the tie curve and indicate that pole experience curves are not likely to differ materially from the tie experience curves which are based on a larger number of specimens. Service-life experience curves for several of

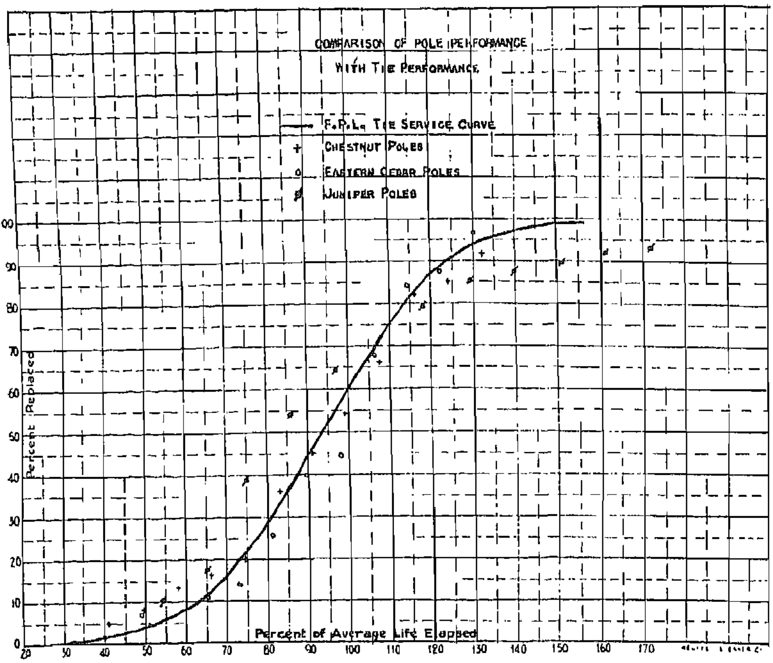


Fig. 173. Comparison of pole performance with tie performance.

the experimental groups have also been prepared and are shown in figure 175*a–c*. These curves have been drawn for only those groups where the removals have been relatively numerous and distributed over the life of the line to the date of the last inspection. The removals in other groups have been either few in number or they have been confined to one or two years so that curves drawn from these data would be of little value.

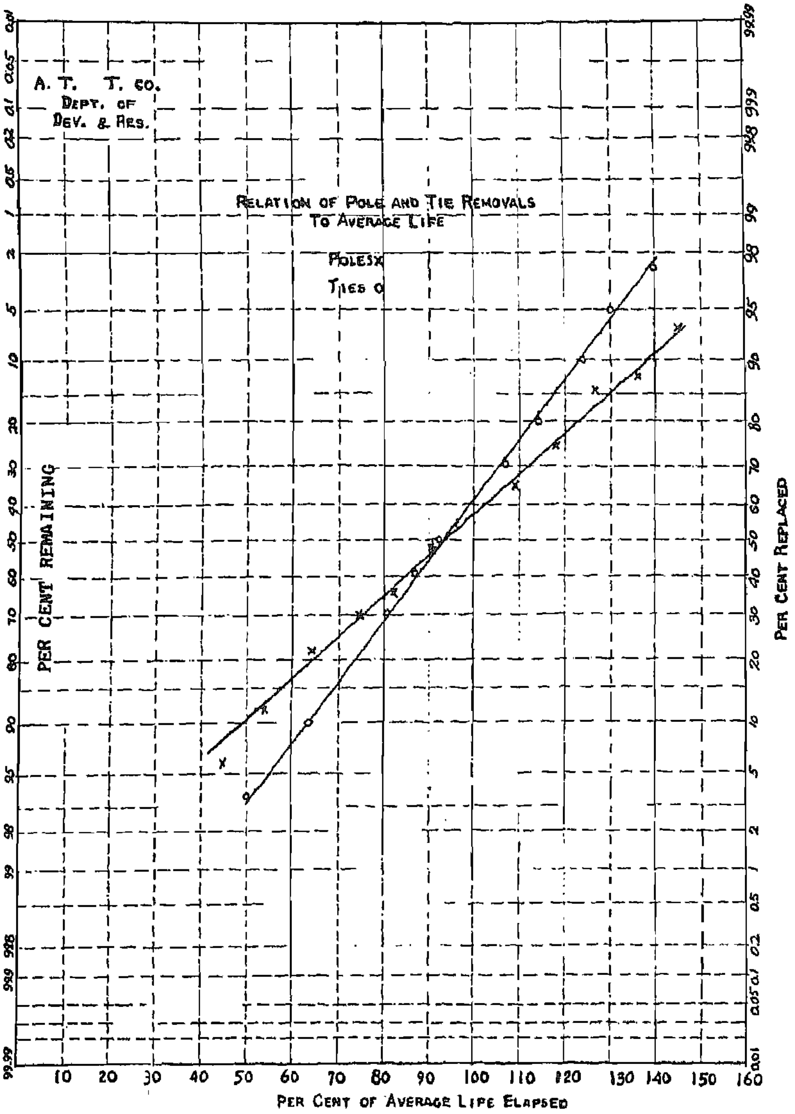


Fig. 174. Relation of pole and tie removals to average life.

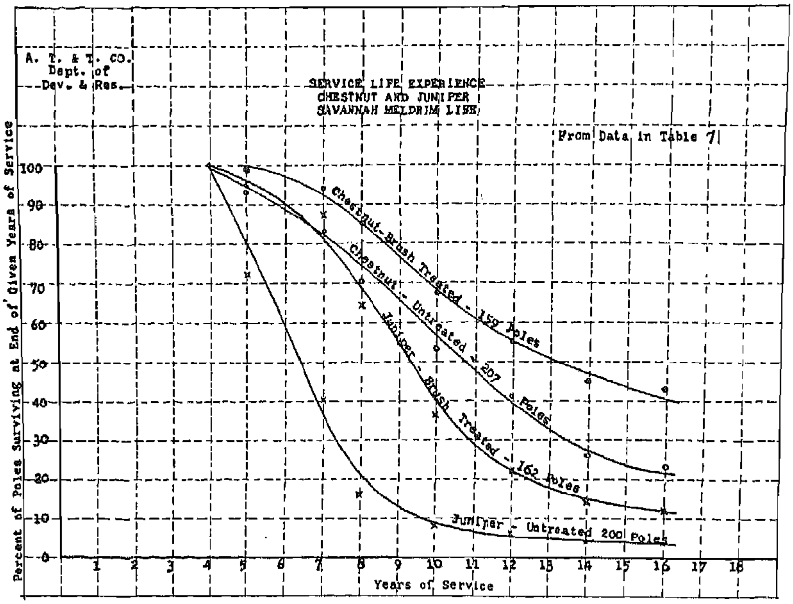
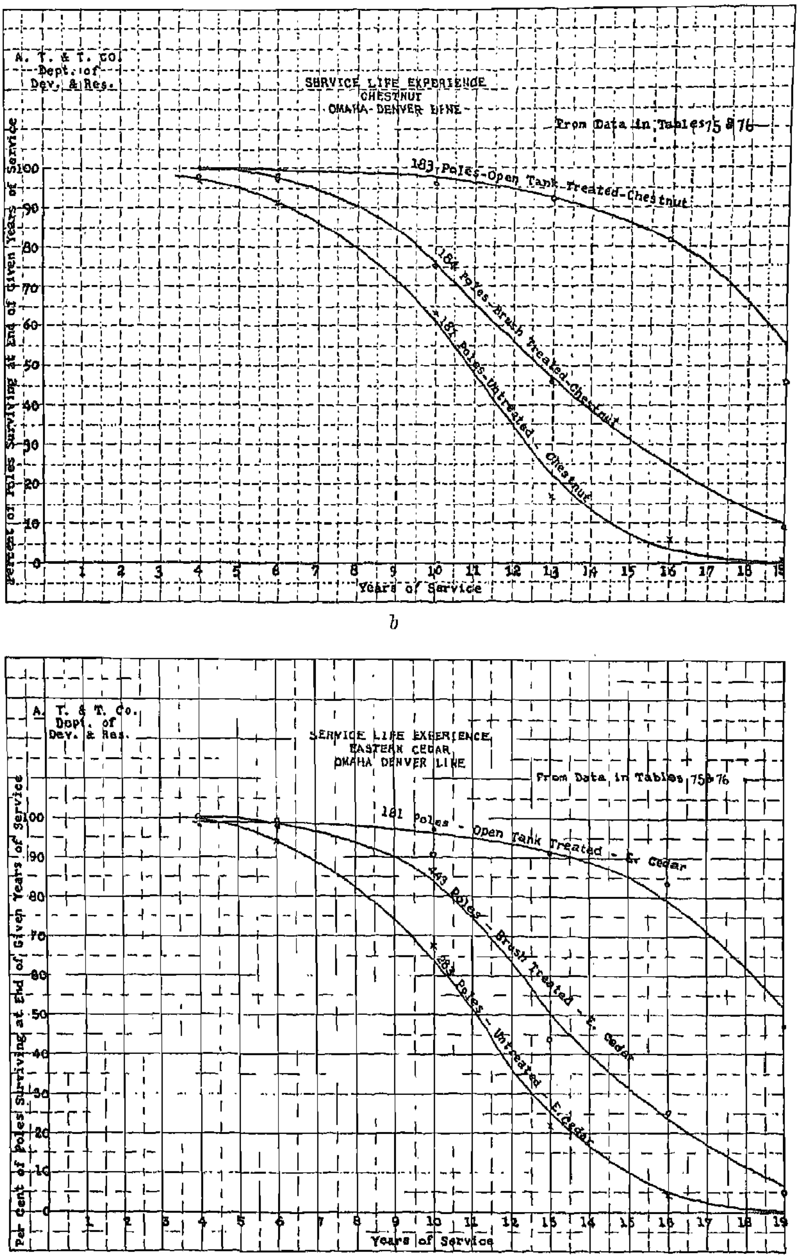


Fig. 175*a*. (See next page.)

LIFE EXTENSION BY TREATMENTS

Butt treatments in these experimental exposures have been applied only to species of timber which in the untreated form show considerable resistance to decay and which had been found usually to suffer impairment by decay in the ground section before the occurrence of impairment in the upper parts of the pole. The application of a butt treatment to a pole has been assumed to result in making it immune to fungus attack for an appreciable period. Three assumptions may be made as to the probable behavior of the pole after the preservative has become so depleted as to permit of the growth of fungi, *viz.*, the rate at which decay progresses may be greater than, less than, or equal to the rate at which it would have progressed had the pole been exposed in an untreated condition.

The removals of open-tank treated poles from the experimental groups are as yet too few in number to support any conclusions on this problem. Most of the decay attack upon the open-tank treated specimens up to the present time has been restricted to one or more rather small areas on the periphery of the ground section leading first to the formation of small pockets of decay opening through the treated layer. Usually decay injury has not spread rapidly from these openings around the circumference of the specimen, and the changes found at successive examinations of a point of attack have shown extension mainly in a radial direction.



b

c

Fig. 175. *a*. Service-life experience, chestnut and juniper poles, Savannah-Meldrim line. *b*. Service-life experience, chestnut, Omaha-Denver line. *c*. Service-life experience, eastern cedar, Omaha-Denver line.

The brush treated specimens, however, having received a materially lighter impregnation with preservative than the open-tank treated specimens, furnish a more complete life experience. In analyzing the rate of decrease in circumference for the untreated and brush treated specimens since the start of decay, it has been found that green untreated lots show little or no change in rate of decrease of circumference with extension of the period of exposure; whereas the seasoned lots, both untreated and brush treated, show substantially larger rates of decrease in circumference as the period of exposure lengthens, with indications that the average annual circumferential decrease after decay starts will be somewhat lower for the treated groups than for the untreated poles.

GENERAL CONCLUSIONS

Because of the fact that many of the test specimens are still in service, conclusions can be reached only in the case of some of the less important problems whose solution has been sought. The possibility of extending the life of poles through preservative treatment is abundantly demonstrated, but the capabilities of the more effective processes of treatment studied can as yet only be estimated.

It has been established that seasoning previous to use does not retard decay of pole timber in contact with the soil and the data would even seem to indicate that seasoning of pole timber to be set untreated may actually hasten decay. Seasoning, however, offers advantages through improvement in treatability of the wood, reduction in weight, and a lessening of subsequent checking. The inception of decay on the treated poles under test is gradually reaching substantial proportions and the indications are that in the cases not already affected, the beginning of decay attack will mainly be dependent upon changes in the quantity and the composition of the preservative retained in the individual poles. The progress of this decay after incidence promises to be slower than the progress of decay in similar seasoned timber which has not been treated.

It may be noted from the data on open-tank treated and brush treated poles that there is evidence that when a given species of timber has been subjected to different processes of treatment, greater average resistance to decay has been found for the process which resulted in greater average penetration and larger average absorption of the preservative. In addition to the influence exerted by the greater quantity of preservative present, the greater resistance to decay characteristic of heartwood as compared to sapwood seems to be a factor contributing to this improved resistance to fungus attack.

REFERENCES

1. Recent results obtained from the preservative treatment of telephone poles. F. L. Rhodes and R. F. Hosford. Trans. A. I. E. E., vol. (1915) pp. 2549–2593.

2. Service tests of treated and untreated poles. P. R. Hicks Report of Overhead Systems Committee to N. E. L. A. (1921) pp. 147–162.

Service tests of treated and untreated poles. R. M. Wirka Report of Overhead Systems Committee to N. E. L. A. (1926) pp. 2–14.

Service tests of treated and untreated poles. R. M. Wirka Serial Report 278–3 of Overhead Systems Committee, N. E. L. A. (Oct. 1927).

TABLE 63

WASHINGTON-NORFOLK LINE

Mortality data

	Sawn specimens		Circular specimens	
Year of inspection Age of line	1914 17th year	1921-23 24th-26th year	1914 17th year	1921-23 24th-26th year
Number of specimens originally placed	1,523	1,523	122	122
Number of specimens inspected	1,457	1,299	118	86
Number of specimens found replaced				
because of decay*	23	26	3	8
for other causes	43	132	1	24
Total eliminated from further inspection	66	158	4	32
Number found sound	1,334	1,077	96	49
Number found decaying	123	222	22	37

* Includes poles attacked by insects.

TABLE 64

WASHINGTON-NORFOLK LINE

Location of initial decay attack

	Sawn specimens		Circular specimens	
Year of inspection Age of line	1914 17th year	1921-23 24th-26th year	1914 17th year	1921-23 24th-26th year
Number of original specimens in service	1,457	1,299	118	86
Number found sound	1,334	1,077	96	49
Poles showing decay first noted in 1914	123	85	22	11
Poles showing decay first noted in 1921-23	......	137	...	26
Centers of decay attack				
in top section	42	38	3	7
in side section	6	7	10	1
in ground section	82	101	16	20
Total*	130	146	29	28

* Some poles show decay attacks in more than one section.

TABLE 65

WASHINGTON-NORFOLK LINE

Causes of decay infections

	Sawn specimens		Circular specimens	
Year of inspection Age of line	1914 17th year	1921-23 24th-26th year	1914 17th year	1921-23 24th-26th year
Number of decay infections found	130	146	30	28
Infections due to failure to secure adequate penetration	4	0	20	5
Infections due to preservative depletion	90	93	3	15
Infections due to checks, shakes, splits, etc.	32	45	6	7
Infections due to mechanical injury including cutoff tops	4	8	1	1

TABLE 66

WASHINGTON-NORFOLK LINE

Insect infestation

	Sawn specimens	Circular specimens		Sawn specimens	Circular specimens
Number of poles attacked by decay	260	48	Number of poles infested by black ants	21	1
Number of poles infested by insects	70	18	Number of poles infested by red ants	5	3
Number of poles infested by termites	51	11	Number of poles infested by borers	2	3

TABLE 67

MONTGOMERY-NEW ORLEANS LINE

Record of removals from service in test sections

(1,602 specimens placed in 1899)

Year	Number replaced on account of decay	Number on which decay had begun replaced for other causes	Number sound when replaced	Total number replaced
Prior to 1915	9	...	18*	27
1915	6	12	119	137
1916	17	2	1	20
1917	3	....	....	3
1918	1	3	1	5
1919	96	27	63	186
1920	6	7	6	19

Number of original specimens in service at second inspection, 1,205.

Year	Number replaced on account of decay	Number on which decay had begun replaced for other causes	Number sound when replaced	Total number replaced
1921	1	8	4	13
1922	3	....	1	4
1923	1	....	....	1
1924	3	....	....	3
1925	69	40	14	123
1926	1	28	9	38

Number of original specimens in service at third inspection, 1,023.

Year	Number replaced on account of decay	Number on which decay had begun replaced for other causes	Number sound when replaced	Total number replaced
1927	64	75	82	221

Number of original specimens left in service after third inspection, 802.
Number of specimens still sound, 180.

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*Concerning these 18 poles, it is only known that they were not replaced on account of decay.

TABLE 68

MONTGOMERY-NEW ORLEANS LINE

Location of initial decay attack

	1915 inspection 16th year	1921 inspection 22nd year	1926-27 inspection 28th year
Number of original specimens found in line	1,575	1,205	1,030*
Number of these found sound	1,069	533	262
Number of these on which decay was first found in 1915 (16th year)	506	337	247
Number of these on which decay was first found in 1921 (22nd year)	.....	335	278
Number of these on which decay was first found in 1926-7 (28th year)	.....	.....	243*
Location of initial decay attack:			
in top section only	32	71	44
in side section only	83	54	52
in ground section only	189	145	85
in both top section and side section	6	11	14
in both top section and ground section	25	28	19
in both side section and ground section	138	20	25
in top, side, and ground sections	33	6	4
Total number of attacks in top section	96	116	81
Total number of attacks in side section	260	91	95
Total number of attacks in ground section	385	199	133
Total number of attacks in all sections	741	406	309

* Includes data on 7 poles removed in the line changes of 1925 (26th year).

TABLE 69

MONTGOMERY-NEW ORLEANS LINE

Causes of decay of infected poles and causes of decay of specimens removed

	1915			1921			1926-27			1915-21 Replaced on account of decay			OD	1921-27 Replaced on account of decay			OD
	T	S	GS	T	S	GS	T	S	GS	T	S	GS		T	S	GS	
Number of specimens removed	....	....	....	....	....	....	....	....	...	10	56	63	51	17	64	61	151
Number of decay infections	96	260	385	116	91	199	81	95	133	....	...	....	....	....	....	....	....
Shallow penetration	7	242	370	1	40	99	....	....	....	1	47	61	34	....	43	60	65
Center decay	23	....	....	19	2	....	11	....	....	3	....	....	4	3	1	....	2
Checks	7	8	8	20	21	....	20	25	9	1	2	....	1	2	8	....	25
Shakes	54	....	....	72	1	....	45	1	....	5	....	....	..	11	....	....	15
Preservative depletion	3	1	1	1	20	94	3	41	120	....	3	1	1	1	7	1	28
Injury to treated layer	2	9	6	3	7	6	2	28	4	....	2	1	2	....	5	...	16
Number where there is no record of cause of decay	....	....	....	....	....	....	....	....	....	....	2	....	9	....	....	....	....

Notes: T=top section; S=side section; GS=ground section; OD=after decay had begun but not on account of it.

TABLE 70

MONTGOMERY-NEW ORLEANS LINE

Insect infestation and woodpecker attack

Test section	Number of original specimens in line 1915	Number of original specimens observed under decay attack to 1927	Insect infestation and damage							Number of specimens attacked by woodpeckers	
			Number of original specimens infested by insects 1915-1927	Number of specimens attacked by termites	Number of specimens infested by ants			Number of specimens attacked by wood-boring beetles			
					Small black	Large black	Red	Round-head	Flat-head	Holes only	Holes and nests
Hurricane (swamp)	219	127	74	11	33	5	16	45	2	....	....
Magazine Point (swamp)	228	61	41	18	23	....	2	19	1	....	....
Dog River	148	123	82	77	6	....	2	16	4	30	5
Grand Bay	147	110	79	74	5	....	3	16	4	27	12
Pascagoula	149	104	61	56	4	....	....	8	3	5	....
Biloxi	164	142	81	55	7	....	19	26	16	12	....
Pass Christian	153	109	88	75	21	1	4	21	2	12	....
Bay St. Louis	203	172	129	113	3	1	7	13	6	10	....
Gentilly	164	136	96	60	51	6	6	15	2	....	....
All sections	1,575	1,084	731	539	153	13	59	179	40	96	17

Method of treatment and preservative*	Number of specimens remaining in line and inspected								Cumulative number of specimens found replaced or dropped from records on account of previously determined unserviceability													
									On account of damage by decay							On account of other causes					
	1909†	1910	1912	1913	1915	1917	1919	1921	1910	1912	1913	1915	1917	1919	1921	1912	1913	1915	1917	1919	1921
JUNIPER-WILMINGTON																					
2 coats Carb. Ave. (A)	24	24	24	22	16	10	10	5	0	0	2	7	11	11	16	0	0	1	3	3	3
2 coats S.P.F. Carb. (B)	19	19	17	15	12	4	3	2	0	2	4	7	15	16	17	0	0	0	0	0	0
2 coats creosote	33	33	32	30	26	10	5	3	0	1	3	7	23	28	30	0	0	0	0	0	0
2 coats wood creo. (E)	24	24	22	18	12	7	5	3	0	1	3	9	14	16	18	1	3	3	3	3	3
2 coats Creolin (F)	23	23	20	18	12	7	5	4	0	3	3	9	14	16	17	0	2	2	2	2	2
3 coats Spirittine (C)	23	23	22	19	14	7	5	5	0	1	4	9	16	18	18	0	0	0	0	0	0
3 coats creosote	13	13	13	9	7	3	2	0	0	0	1	3	7	8	....	0	3	3	3	3	....
1 coat S.P.F. Carb. (B)	3	3	3	2	2	0	0	0	0	0	1	1	3	....	....	0	0	0	0	....	....
1 coat coal tar	24	23	19	13	6	6	4	1	1	5	10	17	17	19	22	0	1	1	1	1	1
1 coat coal tar	12	12	10	6	2	1	0	0	0	1	5	9	10	....	....	1	1	1	1	...	....
Seasoned, none	104	100	66	32	12	5	3	3	4	38	72	92	98	100	100	0	0	0	1	1	1
Green, none	96	94	72	40	17	9	8	5	2	23	53	76	84	85	88	1	3	3	3	3	3
CHESTNUT-PISGAH																					
2 coats Carb. Ave. (A)	18	18	18	18	17	16	14	12	0	0	0	1	2	3	5	0	0	0	0	1	1
2 coats S.P.F. Carb. (B)	18	18	17	16	15	13	10	10	0	1	1	2	4	7	7	0	1	1	1	1	1
2 coats creosote	39	39	39	36	33	25	23	20	0	0	1	4	10	12	15	0	2	2	4	4	4
2 coats wood creo. (E)	24	24	23	21	18	15	14	11	0	0	2	5	8	9	12	1	1	1	1	1	1
2 coats Creolin (F)	23	23	22	21	19	14	10	8	0	1	2	4	9	13	15	0	0	0	0	0	0
3 coats Spirittine (C)	23	23	23	22	20	11	9	8	0	0	1	3	12	14	15	0	0	0	0	0	0
3 coats creosote	6	6	6	5	5	3	1	0	0	0	1	1	3	5	....	0	0	0	0	0	....
1 coat Carb. Ave. (A)	4	4	4	4	4	4	3	1	0	0	0	0	0	1	3	0	0	0	0	0	0
1 coat S.P.F. Carb. (B)	2	2	2	2	2	1	1	1	0	0	0	0	1	1	1	0	0	0	0	0	0
1 coat creosote	2	2	2	2	2	2	0	0	0	0	0	0	0	2	....	0	0	0	0	....	....
1 coat coal tar	20	20	20	18	14	10	7	5	0	0	2	6	10	13	15	0	0	0	0	0	0
1 coat pine tar	3	3	3	3	3	2	1	1	0	0	0	0	0	1	1	0	0	0	1	1	1
1 coat coal tar	8	8	7	7	6	3	1	1	0	1	1	2	5	7	7	0	0	0	0	0	0
1 coat pine tar	4	4	4	4	4	2	2	1	0	0	0	0	2	2	3	0	0	0	0	0	0
Seasoned, none	112	109	101	88	69	46	33	17	3	11	23	41	64	77	93	0	1	2	2	2	2
Green, none	95	94	90	82	73	59	49	35	1	4	12	20	34	44	58	1	1	2	2	2	2

(Continued on page 658)

TABLE 71 *(Concluded)*

Method of treatment and preservative*	Condition of specimens inspected																							
	Number found sound at inspection								Number decaying but not to point of replacement								Number decaying which had reached point of replacement							
	1909	1910	1912	1913	1915	1917	1919	1921	1909	1910	1912	1913	1915	1917	1919	1921	1909	1910	1912	1913	1915	1917	1919	1921
JUNIPER-WILMINGTON																								
2 coats Carb. Ave. (A)	17	12	10	8	1	1	0	0	7	12	12	9	11	9	5	4	0	0	2	5	4	0	5	1
2 coats S.P.F. Carb. (B)	13	11	11	7	2	2	1	0	6	6	4	5	4	1	1	2	0	2	2	3	6	1	1	0
2 coats creosote	25	11	8	6	0	0	0	0	8	21	22	20	14	5	3	3	0	1	2	4	12	5	2	0
2 coats wood creo. (E)	14	14	8	3	1	1	0	0	10	9	13	9	6	4	3	3	0	1	1	6	5	2	2	0
2 coats Creolin (F)	6	1	1	1	0	0	0	0	17	19	19	11	9	5	4	4	0	3	0	6	3	2	1	0
3 coats Spirittine (C)	15	10	6	0	0	0	0	0	8	12	13	15	7	5	4	5	0	1	3	4	7	2	1	0
3 coats creosote	10	5	3	1	0	0	0	....	3	8	9	6	4	2	0	....	0	0	1	2	3	1	2	....
1 coat S.P.F. Carb. (B)	1	1	1	1	0	....	....	....	2	2	1	1	0	....	....	....	0	0	1	0	2	....	....	....
1 coat coal tar	0	0	0	0	0	0	0	0	24	19	14	6	6	4	1	1	0	4	5	7	0	2	3	0
1 coat coal tar	0	0	0	0	0	0	....	....	12	11	6	2	1	0	....	....	0	1	4	4	1	1	....	....
Seasoned, none	0	0	0	0	0	0	0	0	103	68	36	13	6	3	3	2	1	32	30	19	6	2	0	1
Green, none	1	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*95*	*76*	*44*	18	*10*	*8*	5	5	*0*	18	28	22	7	*1*	3	*0*
CHESTNUT-PISGAH																								
2 coats Carb. Ave. (A)	16	14	11	11	4	4	2	2	2	4	7	6	12	11	10	9	0	0	0	1	1	1	2	1
2 coats S.P.F. Carb. (B)	14	12	9	8	4	3	3	2	4	5	8	7	9	8	7	8	0	1	0	1	2	2	0	0
2 coats creosote	28	22	18	17	7	3	1	1	11	17	20	16	21	20	19	19	0	0	1	3	5	2	3	0
2 coats wood creo. (E)	16	8	8	7	1	1	0	0	8	16	13	11	14	13	11	11	0	0	2	3	3	1	3	0
2 coats Creolin (F)	17	14	12	10	4	2	0	0	6	8	9	9	10	9	8	8	0	1	1	2	5	3	2	0
3 coats spirittine (C)	17	11	6	5	1	1	1	1	6	12	16	15	10	8	7	7	0	0	1	2	9	2	1	0
3 coats creosote	4	4	4	2	0	0	0	....	2	2	1	3	3	1	0	....	0	0	1	0	2	2	1	....
1 coat Carb. Ave. (A)	2	2	2	1	0	0	0	0	2	2	2	3	4	3	1	0	0	0	0	0	0	1	2	1
1 coat S.P.F. Carb. (B)	2	2	1	1	0	0	0	0	0	0	1	1	1	1	1	1	0	0	0	0	1	0	0	0
1 coat creosote	1	0	0	0	0	0	....	....	1	2	2	2	2	0	....	....	0	0	0	0	0	2	....	....
1 coat coal tar	1	0	0	0	0	0	0	0	19	20	18	14	12	8	5	5	0	0	2	4	2	2	2	0
1 coat pine tar	0	0	0	0	0	0	0	0	3	3	3	3	3	1	1	1	0	0	0	0	0	1	0	0
1 coat coal tar	0	0	0	0	0	0	0	0	8	7	7	7	3	1	1	1	0	1	0	0	3	2	0	0
1 coat pine tar	0	0	0	0	0	0	0	0	4	4	4	4	2	2	1	1	0	0	0	0	2	0	1	0
Seasoned, none	0	0	0	0	0	0	0	0	111	101	89	71	48	33	17	14	1	8	12	17	21	13	16	3
Green, none	0	0	0	0	0	0	0	0	95	91	82	74	62	51	36	34	0	3	8	8	11	8	13	1

* Note—The letters (A), (B), etc., are the designations for the preservative given in the 1915 paper. Abbreviations: Carb., Carbolineum; Ave., Avenarius; Creo., Creosote.

† No specimens had been removed prior to 1909 inspection so that this column gives the number of specimens originally installed in 1905.

TABLE 72

Data on Experimental Poles in the Savannah-Meldrim Line

(Chestnut and Juniper)

Method of treatment and preservative*	Average increase in weight from treatment (pounds)	Number of specimens originally installed	Average decrease in circumference per year under observation (in inches) for all specimens								Insect infestation Number of specimens infested			
			1909	1910	1912	1913	1915	1917	1919	1921	Total	By termites	By ants	By borers
JUNIPER-WILMINGTON														
2 coats Carb. Ave. (A)	3.6	24	.02	.21	.38	.70	.83	.90	1.00	.99	14	11	7	....
2 coats S.P.F. Carb. (B)	3.7	19	.03	.48	.56	.84	1.16	1.19	1.17	1.16	12	9	6	...
2 coats creosote	4.9	33	.05	.24	.50	.86	1.05	1.12	1.13	1.11	26	22	16	1
2 coats wood creo. (E)	4.4	24	.07	.43	.57	1.03	1.14	1.12	1.15	1.13	13	13	4	....
2 coats Creolin (F)	6.0	23	.21	.66	.66	1.09	1.15	1.21	1.21	1.18	15	12	8	1
3 coats Spirittine (C)	4.7	23	.04	.32	.62	1.10	1.22	1.19	1.20	1.16	16	11	13	....
3 coats creosote	7.0	13	.06	.14	.33	.73	.97	1.01	1.05	....	5	4	2	...
1 coat S.P.F. Carb. (B)	1.6	3	.16	.53	.74	.76	1.41	....	....	....	2	2	1	..
1 coat coal tar	....	24	.85	1.35	1.52	1.75	1.69	1.65	1.63	1.62	13	12	5	1
1 coat coal tar	....	12	.58	1.01	1.07	1.25	1.25	1.26	....	....	8	7	4	....
Seasoned, none	....	104	.85	1.74	1.90	2.02	2.02	2.00	1.99	1.97	55	52	9	1
Green, none	....	96	1.01	1.15	1.32	1.39	1.35	1.33	1.33	1.31	52	48	13	...
CHESTNUT-PISGAH														
2 coats Carb. Ave. (A)	4.1	18	.01	.02	.03	.23	.37	.45	.55	.58	11	11	1	....
2 coats S.P.F. Carb. (B)	4.2	18	.10	.22	.21	.34	.54	.66	.71	.70	11	11	2	...
2 coats creosote	6.9	39	.07	.08	.16	.34	.64	.71	.83	.79	27	25	2	4
2 coats wood creo. (E)	5.4	24	.05	.16	.44	.65	.88	.95	1.05	1.00	18	16	4	....
2 coats Creolin (F)	6.4	23	.04	.22	.32	.47	.92	1.04	1.17	1.13	16	16	....	....
3 coats Spirittine (C)	6.7	23	.02	.14	.36	.63	1.15	1.20	1.16	1.11	15	15	3	1
3 coats creosote	6.5	6	.18	.20	.50	.64	1.64	1.94	2.01	....	4	4	....	...
1 coat Carb. Ave. (A)	3.7	4	.03	.04	.06	.09	.63	.77	1.15	1.17	3	3	1	....
1 coat S.P.F. Carb. (B)	3.2	2	.00	.00	.01	.09	.99	.97	.93	.87	1	1	....	....
1 coat creosote	5.1	2	.05	.19	.23	.39	.64	1.14	....	....	2	2	....	....
1 coat coal tar	....	20	.28	.45	.71	1.10	1.29	1.35	1.41	1.36	13	13	.	....
1 coat pine tar	....	3	.18	.21	.27	.32	.61	.98	.93	.89	3	1	....	2
1 coat coal tar	....	8	.37	.69	.62	.76	1.26	1.34	1.33	1.31	4	3	1	..
1 coat pine tar	....	4	.26	.41	.38	.37	.95	.99	1.01	.98	2	2	....	...
Seasoned, none	....	112	.45	.84	1.07	1.29	1.57	1.63	1.66	1.63	66	63	7	....
Green, none	....	95	.40	.50	.60	.72	.86	.88	.94	.90	57	57	3	1

* Note.—The letters (A), (B), etc., are the designations for the preservative given in the 1915 paper. Abbreviations: Carb., Carbolineum; Ave., Avenarius; Creo., Creosote.

TABLE 73

Data on Experimental Poles in the Buffalo-Warren Line
(Chestnut)

Method of treatment and preservative	Average increases in weight from treatment (pounds)	Number of specimens remaining in line and inspected						Cumulative number of specimens found replaced or dropped from records on account of previously determined unserviceability					
								On account of damage by decay			On account of other causes		
		1910*	1913	1916	1919	1922	1925-6	1919	1922	1925-6	1919	1922	1925-6
2 coats Carb. Ave. (A)	4.6	66	66	66	66	66	66	0	0	0	0	0	0
2 coats SPF Carb. (B)	4.4	66	66	66	66	66	60^{3}‡	0	0	0	0	0	3
2 coats creosote..........	7.5	85	85	85	84^{1}	83	82^{2}	0	0	0	1	1	1
2 coats wood creo. (E)	5.4	50^{1}	50	50	49	48	47	0	1	1	1	1	2
2 coats Creolin (F)....	7.6	63	63	62^{1}	61^{1}	61^{1}	59^{1}	1	1	1	0	0	2
1 coat Carb. Ave. (A)	2.0	8	8	8	8	8	8	0	0	0	0	0	0
1 coat S.P.F. Carb. (B)	3.5	10	10	10	10	10	10	0	0	0	0	0	0
1 coat wood creo. (E)	2.4	21	21	21	21	21	21	0	0	0	0	0	0
1 coat Creolin (F)......	3.4	16	16	16	16	16	15^{1}	0	0	0	0	0	0
1 coat coal tar..............	—†	48	48	48	48	48	46^{2}	0	0	0	0	0	0
Tank seasoned creo..	22.4	154	154	154	150^{1}	148^{1}	147^{2}	0	0	0	3	5	5
Tank green creosote..	15.2	28	28	28	28	28	28	0	0	0	0	0	0
Seasoned, none...........	None	358	358	358	355^{1}	343^{1}	312^{12}	2	13	31	0	1	3
Green, none	None	192	192	192	192	190^{2}	178^{9}	0	0	3	0	0	2

Method of treatment and preservative	Condition of specimens inspected															
	Number found sound						Number decaying but not to point of replacement						Number decaying which had reached point of replacement			
	1910	1913	1916	1919	1922	1925-6	1910	1913	1916	1919	1922	1925-6	1916	1919	1922	1925-6
2 Coats Carb. Ave. (A)...............	59	42	36	24	21	18	7	24	30	42	45	45	0	0	0	3
2 coats S.P.F. Carb. (B).............	57	32	28	17	15	9	9	34	38	49	51	40	0	0	0	2
2 coats creosote.............................	77	58	51	35	31	18	8	27	34	49	52	64	0	0	0	0
2 coats wood creosote (E)...........	43	22	15	8	4	4	6	28	35	40	44	40	0	1	0	3
2 coats Creolin (F)........................	21	1	0	0	0	0	42	62	61	61	61	56	1	0	0	3
1 coat Carb. Ave. (A).....................	5	0	0	0	0	0	3	8	8	8	8	7	0	0	0	1
1 coat S.P.F. Carb. (B)................	8	1	1	0	0	0	2	9	9	10	10	8	0	0	0	2
1 coat wood creosote (E).............	1	0	0	0	0	0	20	21	21	21	21	21	0	0	0	0
1 coat Creolin (F)...........................	0	0	0	0	0	0	16	16	16	16	16	13	0	0	0	2
1 coat coal tar..................................	1	0	0	0	0	0	47	48	48	48	48	41	0	0	0	5
Tank seasoned creosote................	154	152	150	142	131	117	0	2	4	8	17	30	0	0	0	0
Tank green creosote.......................	28	27	26	26	23	22	0	1	2	2	5	6	0	0	0	0
Seasoned, none................................	1	0	0	0	0	0	357	358	356	344	325	271	2	11	18	41
Green, none.......................................	0	0	0	0	0	0	192	192	192	192	187	170	0	0	3	8

Method of treatment and preservative	Average decrease in circumference per year under observation (in inches)						Insect infestation (number of specimens infested)		
	For all specimens								
	1910	1913	1916	1919	1922	1925-6	Total	Ants	Borers
2 coats Carb. Ave. (A)........................	.01	.02	.03	.08	.12	.13	8	7	2
2 coats S.P.F. Carb. (B)....................	.01	.04	.05	.07	.09	.10	2	1	1
2 coats creosote....................................	.002	.02	.03	.05	.06	.07	5	5	....
2 coats wood creosote (E)..................	.01	.05	.07	.10	.12	.14	3	3	....
2 coats Creolin (F)..............................	.08	.16	.20	.21	.22	.23	10	6	4
1 coat Carb. Ave. (A)...........................	.04	.19	.20	.28	.37	.36	3	4	....
1 coat S.P.F. Carb. (B).......................	.01	.08	.17	.24	.32	.34	1	1	1
1 coat wood creosote (E)....................	.08	.17	.17	.17	.17	.17	4	4	2
1 coat Creolin (F).................................	.18	.23	.24	.21	.24	.23	2	2	....
1 coat coal tar..	.19	.25	.25	.26	.28	.28	9	6	5
Tank seasoned creosote......................	.000	.000	.001	.002	.005	.009	3	3	....
Tank green creosote............................	.000	.001	.003	.003	.004	.006	....	....	....
Seasoned, none.....................................	.20	.27	.28	.32	.37	.38	103	61	50
Green, none..	.24	.28	.25	.24	.26	.26	49	24	32

* No specimens had been removed prior to 1910 inspection so that this column gives the number of specimens originally installed in 1905. † Not recorded. ‡ Numbers denote poles in line but not inspected because of inaccessibility.

Note.—The letters (A), (B), etc., are the designations for the preservative given in the 1915 paper. Abbreviations: Carb., Carbolineum; Ave., Avenarius; Creo., Creosote.

TABLE 74

DATA ON EXPERIMENTAL POLES IN THE BUFFALO-WARREN LINE

(Chestnut)

Condition of the Line at the End of 1929 Inspection

Method of treatment and preservative	Number of specimens originally installed	Number of specimens replaced or recommended for replacement			Number of specimens remaining in line		
		On account of damage by decay	On account of other causes	Total	Sound	Decayed	Total
2 coats Carb. Ave. (A)	66	10	4	14	8	44	52
2 coats S.P.F. Carb. (B)	66	7	5	12	4	50	54
2 coats creosote	85	7	1	8	9	68	77
2 coats wood creosote (E)	50	9	3	12	1	37	38
2 coats Creolin (F)	63	7	2	9	0	54	54
1 coat Carb. Ave. (A)	8	3	0	3	0	5	5
1 coat S.P.F. Carb. (B)	10	4	0	4	0	6	6
1 coat wood creosote (E)	21	1	0	1	0	20	20
1 coat Creolin (F)	16	4	0	4	0	12	12
1 coat coal tar	48	9	1	10	0	38	38
Tank seasoned creosote	154	13	5	18	103	33	136
Tank green creosote	28	1	4	5	18	5	23
Seasoned, none	358	124	8	132	0	226	226
Green, none	192	26	5	31	0	161	161

Note.—The letters (A), (B), etc., are the designations for the preservative given in the 1915 paper. Abbreviations: Carb., Carbolineum; Ave., Avenarius; Creo., Creosote.

TABLE 75

DATA ON EXPERIMENTAL POLES IN THE OMAHA-DENVER LINE

(Chestnut and Eastern Cedar)

Group of specimens	Method of treatment and preservative*	Average increase in weight from treatment (pounds)	Number of specimens originally installed	Number of specimens remaining in line and inspected				
				1914	1916	1920	1923	1926
CHESTNUT								
Parkton	2 coats Carb.	4.9	92	91	92	89	71	49
Parkton	2 coats creo	4.7	92	92	92	85	62	33
Parkton	Open tank creo	21.6	183	180	180	178	172	155
Parkton	None	None	181	180	174	144	101	29
EASTERN CEDAR								
Escanaba	2 coats Carb.	3.9	91	91	91	89	77	54
Escanaba	2 coats creo	4.4	95	95	95	92	77	39
Escanaba	Open tank creo	49.8	138	135	132	132	121	112
Escanaba	Tank green creo	8.4	43	43	43	43	43	41
Escanaba	None	None	96	96	93	86	54	15
Lincoln	2 coats Carb.	—†	83	83	83	83	80	56
Lincoln	2 coats creo	2.8	90	90	90	90	63	44
Lincoln	None	None	100	100	100	79	42	11
Seward	2 coats Carb.	—†	79	79	79	71	41	19
Seward	2 coats creo	—†	88	88	87	87	46	18
Seward	None	None	87	87	86	75	28	10
N. Platte	2 coats Carb.	0.87	100	100	100	59	53	50
N. Platte	2 coats creo	0.81	101	101	101	53	50	47
N. Platte	None	None	98	98	97	46	37	30

* All specimens were seasoned except one group of open-tank treated cedar. † Not recorded.

Note.—Abbreviations: Carb., Carbolineum; Ave., Avenarius; Creo., Creosote.

(Continued on page 662)

TABLE 75 *(Concluded)*

Group of specimens	Method of treatment and preservative*	Cumulative number of specimens found replaced or dropped from records on account of previously determined unserviceability								
		On account of damage by decay				On account of other causes				
		1916	1920	1923	1926	1914	1916	1920	1923	1926
CHESTNUT										
Parkton	2 coats Carb.	0	3	20	42	0	0	0	1	1
Parkton	2 coats creo.	0	7	30	58	0	0	0	0	1
Parkton	Open tank creo.	0	1	4	9	3	3	4	7	19
Parkton	None	4	34	76	146	1	3	3	4	6
EASTERN CEDAR										
Escanaba	2 coats Carb.	0	2	10	27	0	0	0	4	10
Escanaba	2 coats creo.	0	3	15	45	0	0	0	3	11
Escanaba	Open tank creo.	0	0	0	0	3	6	0	17	26
Escanaba	Tank green creo.	0	0	0	0	0	0	0	0	2
Escanaba	None	3	9	37	76	0	0	1	5	5
Lincoln	2 coats Carb.	0	0	3	27	0	0	0	0	0
Lincoln	2 coats creo.	0	0	9	23	0	0	0	18	23
Lincoln	None	0	21	50	74	0	0	0	8	15
Seward	2 coats Carb.	0	8	28	48	0	0	0	10	12
Seward	2 coats creo.	0	0	35	59	0	1	1	7	11
Seward	None	0	11	55	72	0	1	1	4	5
N. Platte	2 coats Carb.	0	1	2	5	0	0	40	45	45
N. Platte	2 coats creo.	0	3	5	7	0	0	45	46	47
N. Platte	None	0	1	3	9	0	1	51	58	59

Group of specimens	Method of treatment and preservative*	Condition of specimens inspected														
		Number found sound					Number decaying but not to point of replacement					Number decaying which had reached point of replacement				
		1914	1916	1920	1923	1926	1914	1916	1920	1923	1926	1914	1916	1920	1923	1926
CHESTNUT																
Parkton	2 coats Carb.	35	21	3	1	1	56	69	71	40	34	0	2	15	21	14
Parkton	2 coats creo.	8	3	0	0	0	84	85	64	35	19	0	4	21	27	14
Parkton	Open tank creo.	177	172	146	120	74	3	7	30	48	75	0	1	2	4	6
Parkton	None	0	0	0	0	0	176	165	114	31	11	4	9	30	70	18
EASTERN CEDAR																
Escanaba	2 coats Carb.	63	43	35	19	13	28	47	50	41	29	0	1	4	17	12
Escanaba	2 coats creo.	24	7	1	0	0	71	86	85	47	12	0	2	6	30	27
Escanaba	Open tank creo.	135	132	132	121	107	0	0	0	0	5	0	0	0	0	0
Escanaba	Tank green creo.	42	42	41	35	25	1	1	2	8	13	0	0	0	0	3
Escanaba	None	0	0	0	0	0	96	91	73	25	3	0	5	16	34	12
Lincoln	2 coats Carb.	32	4	2	0	0	51	79	79	57	47	0	0	2	23	9
Lincoln	2 coats creo.	45	13	12	7	4	45	77	71	41	29	0	0	7	15	11
Lincoln	None	0	0	0	0	0	100	97	60	25	3	0	3	19	17	8
Seward	2 coats Carb.	22	10	9	2	1	57	64	58	19	11	0	5	4	20	7
Seward	2 coats creo.	29	7	6	1	1	59	80	75	19	11	0	0	6	26	6
Seward	None	1	0	0	0	0	86	78	59	11	4	0	8	16	17	6
N. Platte	2 coats Carb.	72	63	40	28	23	28	36	18	22	26	0	1	1	3	1
N. Platte	2 coats creo.	72	58	30	27	22	29	40	21	21	24	0	3	2	2	1
N. Platte	None	0	0	0	0	0	98	96	44	31	27	0	1	2	6	3

* All specimens were seasoned except one group of open-tank treated cedar. † Not recorded.

Note.—Abbreviations: Carb., Carbolineum; Ave., Avenarius; Creo., Creosote.

TABLE 76

DATA ON EXPERIMENTAL POLES IN THE OMAHA-DENVER LINE

(Chestnut and Eastern Cedar)

Condition of the Line at the End of 1929 Inspection

Group of specimens	Method of treatment and preservative*	Number of specimens originally installed	Number of specimens replaced or recommended for replacement			Number of specimens remaining in line		
			On account of damage by decay	On account of other causes	Total	Sound	Decayed	Tota
CHESTNUT								
Parkton	2 coats Carb.	92	71	6	77	1	14	15
Parkton	2 coats creo.	92	88	2	90	0	2	2
Parkton	Open tank creo.	183	39	60	99	54	30	84
Parkton	None.	181	174	6	180	0	1	1
EASTERN CEDAR								
Escanaba	2 coats Carb.	91	65	12	77	8	6	14
Escannba	2 coats creo.	95	82	11	93	0	2	2
Escanaba	Open tank creo.	138	0	79	79	58	1	59
Escanaba	Tank green creo.	43	9	8	17	17	9	26
Escanaba	None.	96	91	5	96	0	0	0
Lincoln	2 coats Carb.	This gro	up not ins	pected in	1929			
Lincoln	2 coats creo.	90	62	23	85	3	2	5
Lincoln	None.	100	85	15	100	0	0	0
Seward	2 coats Carb.	79	66	12	78	0	1	1
Seward	2 coats creo.	88	77	11	88	0	0	0
Seward	None.	87	82	5	87	0	0	0
N. Platte groups		These gr	oups not	inspected	in 1929			

* All specimens were seasoned except one group of open-tank treated cedar.

Abbreviations: Carb., Carbolineum; Ave., Avenarius; Creo., Creosote.

TABLE 77

DATA ON EXPERIMENTAL POLES IN THE OMAHA-DENVER LINE

(Chestnut and Eastern Cedar)

Group of specimens	Method of treatment and preservative	Specimens originally installed	Average decrease in circumference per year under observation (in inches) all specimens					Insect infestation number of poles infested				Woodpecker attack			
												Specimens where decay had begun		On sound specimens	
			1914	1916	1920	1923	1926	Total	By termites	By ants	By borers	Total	Causes replacement	Total	Causes replacement
CHESTNUT															
Parkton	2 coats Carb.	92	.17	.35	.51	.66	.71	84	15	16	82	3	1	....	....
Parkton	2 coats creo.	92	.50	.80	.86	.96	1.00	79	10	16	78	1	....	....	....
Parkton	Open tank creo.	183	.002	.02	.04	.08	.11	64	11	14	54	2	1	6	2
Parkton	None	181	.92	1.11	1.07	1.18	1.21	157	26	42	149	3	....	....	....
EASTERN CEDAR															
Escanaba	2 coats Carb.	91	.11	.26	.27	.40	.43	51	8	5	47	2	2	....	....
Escanaba	2 coats creo.	95	.36	.61	.54	.64	.65	66	11	16	60	5	1	....	....
Escanaba	Open tank creo.	138	.000	.000	.000	.000	.000	....	....	....	....	....	....	15	15
Escanaba	Tank green creo.	43	.002	.004	.004	.04	.14	4	....	2	3	....	....	2	1
Escanaba	None	96	.77	.85	.69	.69	.71	42	10	13	30	5	....	....	....
Lincoln	2 coats Carb.	83	.17	.49	.52	.62	.71	63	15	17	63	3	....	....	....
Lincoln	2 coats creo.	90	.20	.39	.41	.59	.62	56	6	13	52	1	....	....	....
Lincoln	None	100	.78	.85	.75	.80	.72	32	10	7	25	3	....	....	....
Seward	2 coats Carb.	79	.36	.60	.47	.51	.52	30	....	1	30	2	....	....	....
Seward	2 coats Creo.	88	.32	.49	.43	.48	.50	42	1	3	39	....	....	....	....
Seward	None	87	.75	.91	.68	.74	.72	28	1	5	27	2	....	....	....
N. Platte	2 coats Carb.	100	.13	.16	.14	.12	.13	22	2	2	19	3	....	....	....
N. Platte	2 coats creo.	101	.14	.19	.17	.15	.18	20	....	1	20	....	....	....	....
N. Platte	None	98	.44	.41	.34	.34	.33	17	1	1	16	1	....	....	....

TABLE 78

SERVICE RECORDS OF EXPERIMENTAL POLES

Experimental lots	Number of specimens installed	Number replaced in stated year of service†																	Number of specimens replaced		Average life (years)
		3	4	5	6	7	8	9	10	11	12	13	14	15	16	18	19	20*	22*	24*	For decay	For other causes	
EASTERN CEDAR																							
Escanaba—untreated	96	0	..	...	5	...	3	..	7	9	6	24	21	2	16	....	3	....	...	....	91	5	12.9
Seward—untreated	87	....	....	1	8	1	..	2	12	11	1	31	9	....	7	..	4	....	....	....	82	5	12.0
Lincoln—untreated	100	....	....	....	3	...	7	7	14	22	5	10	18	3	8	...	3	.	...	...	85	15	12.0
CHESTNUT																							
Parkton—untreated	181	1	....	6	6	3	....	3	33	16	18	29	37	1	17	5	5	..	1	..	174	6	12.3
Sav. Meld.—untreated seasoned	112	....	1	6	4	12	9	9	12	11	8	7	8	8	3	5	..	3	3	3	101	2	11.5
JUNIPER																							
Sav. Meld.—untreated seasoned	104	....	1	19	16	32	13	10	4	3	2	1	..	....	1	1	...	1	...	....	102	1	7.5
Sav. Meld.—untreated green	96	....	....	11	9	32	15	11	4	4	1	1	1	2	....	2	....	3	....	....	90	3	8.3
Sav. Meld.—tar coated	36	...	....	3	3	10	6	6	..	1	2	1	1	2	...	...	...	1	...	....	33	2	8.8
Sav. Meld.—brush treated	162	...	....	4	5	12	23	15	22	22	17	7	6	7	2	7	...	13	..	....	138	11	11.2
All	974	1	2	50	59	102	76	63	108	99	60	111	101	25	54	20	15	21	4	3	896	50	11.0

* Estimated.

† Replacements made on account of decay have been allocated as to date of occurrence on the assumption that the replacement was made promptly after the inspection.

APPENDIX B TO CHAPTER 49

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CHAPTER 50

AN AUDIO-AMPLIFYING SYSTEM FOR TERMITE DETECTION

BY

R. C. BARTON

During the course of the Committee's investigations, the suggestion was made that it might be possible to detect the presence of termites in wood, or structures of wood, by means of an audio-amplifying system. That is to say, it was thought that termite activities within an infested specimen should result in mechanical vibrations which could be "picked up" at the surface of the wood and rendered audible by means of apparatus similar to that employed in radio sets, talking pictures, phonographs using electrical reproduction, and other such devices. In order to test this idea, the aid of The Pacific Telephone and Telegraph Company's engineers was enlisted and experiments were made using an amplifying system assembled from apparatus readily available in the Telephone Company's laboratory.

The essential elements of the system used in these experiments are illustrated in figure 176. As indicated above, none of the apparatus used was designed especially for the purpose. An important element in such a system is the device used to pick up the vibrations at their source. One of the devices used is shown in the foreground of the illustration resting on the cylindrical wood specimen. This particular instrument is an electrical phonograph reproducer and its function in this system, just as in a modern phonograph, is to effect variations, or modulation, in the current flowing in the associated electrical circuit, such variations being of the same form as those felt by the reproducer needle, which rests on the vibrating surface. Other available pick-up devices were tried with some success, but the phonograph unit appeared to give the best performance under the particular conditions of use in this experiment. One of the available devices was a stethoscope transmitter, an instrument designed for use with the electrical stethoscope, which is employed by the medical profession to permit a number of observers to listen to chest and other sounds in medical patients. When associated with electrical filters, part of such sounds may be exaggerated or subordinated as desired. On the table (fig. 176), the article at the extreme left end in the foreground is one of these transmitters.

The output of the reproducer, or pick-up unit, is delivered to an amplifier whose function, like that of a radio receiving set, is to increase the amplitude of the vibrations produced by the pick-up unit and raise the power level to a point suitable for delivery to either a telephone receiver or a loud speaker.

Referring to the cut, a pair of head phones will be seen on the table at the left end and a cone-type loud speaker in the background on the right end. The output of the amplifier could be delivered to either of these, as desired.

Two voice frequency amplifiers, shown in the center of the table, were used to raise the power level, as just mentioned. It was found that an amplifier gain of from eighty to one hundred decibels was required to give satisfactory results. By this is meant that the power received from the pick-up unit had to be increased anywhere from a hundred million to ten billion times before it was sufficient to actuate the receivers or loud speaker. The decibel, which is a unit of measurement used to express the efficiency of communication circuits, is defined as corresponding to a power ratio of $10^{0.1}$, so that a gain of ten decibels implies a power ratio of 10, a gain of twenty decibels a ratio of 10^2, and a gain of eighty decibels a ratio of 10^8. Expressed in this way, it may be stated that the two voice frequency amplifiers when used together were capable of providing a gain of one hundred and twenty decibels, or an increase of a million million in power.

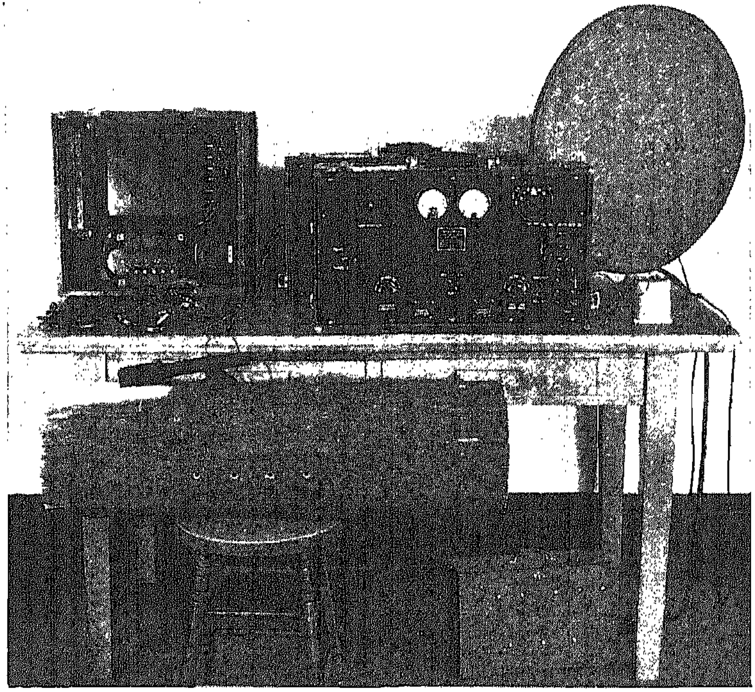

Fig. 176. An audio-amplifying device constructed in an attempt to develop a practical method of detecting termites in structures.

Extraneous vibrations which enter an audio-amplifying system either from mechanical or electrical sources may interfere with those which it is the prime function of the system to detect. Thus, people walking or talking in the room might set up mechanical vibrations in the specimen, or electro magnetic disturbances generated by the operation of nearby electrical elevators or passing motor cars might enter the system, particularly if no effort at shielding is made, and these, being amplified, would be delivered to the receiver or loud speaker, thus masking the sounds caused by the termites. It was therefore desirable to employ means to filter out some of these, together with extraneous "noises" generated within the amplifier.

The cabinet shown on the table in the left background contains a number of electrical wave filters whose function is to attenuate undesirable vibrations. Such filters are able to discriminate between vibrations of different frequencies and are designated as high pass, low pass, or band pass filters, according as they are designed to pass frequencies above a certain limit, below a certain limit, or between such limits. In the tests, filters with the following characteristics were used:

High pass	*Low pass*	*Band pass*
300 cycles	300 cycles	900 to 1100 cycles
3000 cycles	500 cycles	
5000 cycles	700 cycles	
	1100 cycles	
	1800 cycles	

These filters were placed between the output of the amplifier and the receivers in order that the amplifier noise, as well as other interfering noises, might be attenuated.

All electrical circuits offer some impedance to the flow of energy. When two circuits, such as the ouput of the amplifier and the input of the loud speaker used, are connected, the condition for maximum power transfer is obtained when the impedances are equal. Since this condition did not obtain for the particular apparatus employed, a transformer having a pair of windings suitable for matching these impedances was inserted. This transformer is shown on the right-hand end of the table in front of the cone.

Listening tests made in the laboratory proved that it was not difficult to detect the presence of termites in timber through the use of a system such as has been described above. The sound effects produced by the termites could be heard distinctly even without filters, although their use, particularly the low pass, in the laboratory and elsewhere indoors, materially improved the performance. Of course, more gain in the amplifier was required when the filters were in use.

Demonstrations using the loud speaker were especially successful, and at a general meeting of the Termite Investigations Committee at the Clift Hotel in San Francisco, sound effects were made clearly audible to an audience of fifty people.

In most cases it was necessary to excite the termites by tapping or disturbing the specimen of wood before their activities became audible. The sound effect produced was variously described by different listeners, probably not because they heard it differently but because their choice of similes was different. One description, perhaps as good as any, likened the effect to that produced by continuously dropping a great many grains of rice a short distance onto a hard surface. From this description, a synthesis of many discrete elements of sound will be inferred. Since biological investigators have reported that soldier termites warn their colony of impending danger by clapping the horny ends of their mandibles together and rapping their heads against the surrounding wood while they and the workers move restlessly about, it may be a fair guess that the sound heard in the listening tests resulted from these activities. It was noticeable that the output of sound seemed to commence, vary, or cease as though by command.

Field tests, made out-of-doors, were not so successful as those made in the laboratory or elsewhere indoors. Those made in noisy districts were negative, due to the excessive interference. In a relatively quiet district, pole tests indicated that termites could not be heard with sufficient certainty to make such tests of any commercial value. High, low, and band pass filters were tried, but the interfering noises covered such a wide range that it did not appear to be practicable to eliminate them by this means. The principal cause of interference in the case of poles was attributed to the action of the wind on the wires, and in the case of live trees, which were also tested, it was attributed to the action of the wind on the leaves.

The apparatus assembled for this experiment would probably be too costly for the practical termite operator, but the tests prove that the method is satisfactory for laboratory work and indicate that for use in buildings, where some control of interfering noises might be had during testing operations, less expensive equipment would suffice. Under these conditions, the filter network, if required, could be simplified, an amplifier of smaller gain capacity used, and the loud speaker would, of course, not be required. Further investigation might show that a more sensitive pick-up device could be found that would permit further reduction in the gain required. These improvements, and doubtless others, might be expected to follow any extended research by competent investigators if the demand should warrant this research. In the majority of cases in buildings where termite infestation is suspected, it would probably be cheaper to remove enough wood to reveal the extent of damage. On the other hand, in cases where the audio-amplifying method is applicable, it might afford some satisfaction to have the advance assurance that the cost and property damage incident to such removal are unavoidable.

CHAPTER 51

RAILROAD STRUCTURES

BY

W. H. KIRKBRIDE

I. RAILROAD SIGNAL LINES

DISCUSSION

While we should like very much to be able to present in more detail a statement of the termite situation in the 135,000 signal poles of the Southern Pacific Company, Pacific Lines, showing incidence of attack, species involved, and monetary value of the damage done, this is not entirely possible. We can, however, show the results of surveys and individual inspections on sections of our lines, indicating in a general way the types of termites and extent of damage found; and we can show the cost of replacing and repairing these pole lines, and an estimate of how much of this is due to termite damage.

The surveys mentioned are listed in Table 79; the individual inspections are listed in Table 80. Reports of damage and collections of specimens were sent in from every division, except the Rio Grande, which is east of the territory to which the activities of the Termite Investigations Committee were confined.

Early in 1925, when the presence of termites in the State of California was becoming recognized as a serious factor, the aforementioned individual inspections of the Southern Pacific signal pole lines were being made to determine what damage was being done by these pests. Termite infestation was found to be present in the majority of our lines in California, Oregon, Nevada, and Arizona. Redwood, Douglas fir, Port Orford cedar, and western red cedar were attacked, and even creosote butt-treated poles were not spared. Crossarms in many instances were badly eaten. The pole lines which suffered damage beyond repair were replaced as soon as money was available and conditions permitted. In cases where damage was not beyond repair, poles were either stubbed or cut off and dropped down. Crossarms were also replaced when it became necessary to do so. The actual replacements within the last eight years are listed in Table 81. Over this period the aggregate expense amounted to $183,000, which gives us an average of approximately $3.19 per mile per year, or an average per annum cost of $23,000. How much of this annual replacement figure can be charged to termites is not, of course, certain; but reliable estimates place the proportion at around 40 per cent, or $9,200 per annum. In addition to this, we have an ordinary signal pole repair program which approximates $14,000 annually.

TABLE 79

SURVEYS TO DETERMINE EXTENT OF TERMITE ACTIVITIES ON SOUTHERN PACIFIC COMPANY SIGNAL POLE LINES

District	Kind of poles	Termite activity reported
1. Beaumont to Banning, Calif., 1928	Untreated fir and cedar, 22 years old; practically all stubbed	All attacked near ground line by subterranean and dry-wood varieties
2. Garnet to Indio, Calif., 1928	Untreated fir and cedar, 22 years old; line renewed	Practically all attacked
3. Globe-Miami, Ariz., Winkleman and Vicinity, Hayden Jct. and Vicinity, Phoenix, Florence, Tucson and Winkleman, 1929	Principally untreated poles; some creosote butt-treated	Extensive infestation by dry-wood varieties; also *Heterotermes*
4. Portland-Corvallis Electric Line, Ore., 1931	800 butts brushed with creosote 300 butts open-tank treated 400 untreated	30% infested 10% infested 60% infested Both subterranean and damp-wood termites were found
5. Weed, Calif., to Wall Creek, Ore., 1931	Butt-treated Douglas fir, 12 to 14 years in service; a few butt-treated cedar, and some untreated. This survey indicated that poor treatment resulting from the inherent uncertainty of the open-tank process was largely responsible for the failures	About 50% were decayed, and about 20% attacked by *Zootermopsis*, a few attacked by *Reticulitermes*
6. Black Butte, Calif., to Crescent Lake, Ore., 1931	Butt-treated Douglas fir, constructed 1925-1926. These poles were unseasoned when treated and creosote penetration was practically nil. Untreated poles would probably have lasted as long (see fig. 178c)	In 1931, about half the poles had failed from termites, decay, or both. In some cases termites were entirely responsible
7. Sparks-Fernley, Nev., 1931	776 redwood, installed 1905; 42 stubbed up to 1931	Occasional, and not important
8. Harney-Elburz, Nev.	1,252 redwood, installed 1905; 47 stubbed up to 1931	Occasional, and not important
9. Moor-Valley Pass, Nev., 1931	800 redwood, installed 1905; 14 stubbed up to 1931	Occasional, and not important
10. Martinez-Tracy, Calif., 1931	944 redwood, installed 1906; 21 stubbed up to 1931; 64 replaced on account of decay up to 1931	Occasional, and not important
11. Benicia-Sacramento, Calif., 1927	38 miles sawn redwood, installed 1904	Termite damage slight, but about 80% poles badly decayed
12. Chittenden to Gilroy, Calif., 1931	300 redwood, installed 1906; nearly all stubbed by 1931	Estimated three-fourths infested with *Kalotermes* or *Reticulitermes*, or both. Many crossarms infested
13. Guadalupe to Gaviota, Calif., 1931	1,600 redwood, installed 1906; after 14 years, 20% dropped or stubbed; after 18 years, 30% dropped or stubbed; after 18-25 years, 45% dropped or stubbed. Remaining 5% still sound in 1931	Extensive, but no estimate as to percentage. Some which were dropped 1920-24 are being attacked. Principally subterranean

Table 81 also shows the dates that the original signal lines were constructed, as well as the type of the wood poles used. Regardless of this, we are unable to state accurately the actual life of these poles, because of the fact that many of them have been stubbed or dropped down and intermediate poles installed during the interim. We do, however, have an accurate record on the construction of the first signal line along our railroad in Arizona. Thirty-seven miles were built between Yuma and Wellton and 8 miles between Pembroke and Kim. This work was done during 1907, using Texas pine poles pressure-creosoted full length. A recent check shows that these poles are still in excellent condition. This method of treatment was found to be very expensive, and our people were not satisfied at that time that it was of any material benefit to treat the portion of the pole above the top of the ground. Hence, after this installation, our company departed from this method of treating poles and went back to the use of untreated material in its pole lines.

In the year 1901 the first major signal line was constructed on the Tehachapi Mountain. Sawn redwood poles were used. In 1926 when this line was inspected (Ilmon to Tehachapi, 30 miles) all of the poles were found to be badly decayed, weather-split and infested by termites, and were replaced with new cedar poles with creosoted butts (see item 21, Table 81, for replacement figures). Although some of the poles were stubbed or replaced with white cedar poles prior to 1926, the life of the redwood poles in this line seems to be 25 years. In other localities (see items 7–10, Table 79) sawn redwood poles 25 years old are still in excellent condition; on the other hand (items 11–13, Table 79), some redwood pole lines have given between 10 and 20 years' life. Twenty-five years is probably a good average estimate. Round redwood poles, cut from young trees, have seldom lasted more than 7 or 8 years, although a few remained in service for fairly long periods (fig. 178). In locations where white cedar poles were used, we are able to give an approximate average life of about 17 years, although in one or two instances we obtained a life of only 8 to 10 years. In two instances in northern California and Oregon, untreated Douglas fir poles were used. The maximum life of these poles was 10 years when replaced; the average about 6 years.

In the year 1910 our people found by experience that some treatment of the poles was necessary to prevent decay in the ground portion, and after some experiments they adopted, in 1912, the process of butt-treating all poles with creosote oil by the open-tank method. This practice was continued until January 1929, when we adopted the practice of pressure-creosoting poles for their full length. We are now pressure-creosoting crossarms as well. Our company feels that this treatment for poles and crossarms will prove in the long run to be the most economical, because it provides by far the highest resistance to both termites and decay. Therefore, in reviewing Table 81, it should be borne in mind that all poles removed between 1912 and 1929 were replaced with creosote butt-treated cedar poles, while all poles removed subsequent to that date were replaced with poles pressure-creosoted for their full length, either cedar or Douglas fir wood being used.

TABLE 80

TERMITE ATTACKS ON SOUTHERN PACIFIC COMPANY SIGNAL POLES—ARRANGED CHRONOLOGICALLY

Date	Location	Kind of wood	Age, years	Number attacked	Kind of termite and location of attack
10/ 2/25	San Ardo	Cedar	......	......	
10/14/25	Del Monte Jct.-Salinas	Cedar	......	All	
10/14/25	Watsonville Jct.	Cedar	......	......	
10/17/25	Mission Bay Roundhouse	Cedar	......	......	1 foot above ground
10/17/25	Surf	Cedar	......	......	
10/21/25	Burbank to Hewitt	Cedar	......	25%	
10/21/25	Sylmar and San Fernando	Cedar	......	25%	
11/ 3/25	West of Alma	Cedar	......	......	
11/ 5/25	Santa Margarita	Cedar and redwood	......	......	
11/ 5/25	Bradley to *Paso Robles*	Untreated	......	400	
11/ 9/25	Glenwood and Tank Siding	Cedar	......	......	*Reticulitermes hesperus*
11/10/25	¾ mile east of King City	Cedar	......	......	
11/10/25	Welby Yards and 4¼ miles east	Cedar	......	......	
11/13/25	San Luis Obispo, 2510 plus 2512	3 cedar poles	......	......	*Kalotermes minor*
11/13/25	*San Luis Obispo*	Untreated fir	......	......	*K. minor*, to 4 feet above ground
11/13/25	Signal 542, coast	Redwood	......	......	¾-inch penetration 8 inches below ground
11/16/25	*Simi*, Burbank, and MP-603		......	......	
11/16/25	Tennant to Gilroy	Cedar	......	......	*K. minor.*
11/25/25	20-G, east of Hayward		......	......	
11/27/25	Brighton	Redwood	......	......	
12/24/25	East of Bakersfield	Cedar	......	16 out of 19	
1/16/26	Lancaster		......	......	
1/19/26	Warren-Mojave		......	......	
2/ 6/26	Caliente MP-335	Redwood	......	......	
4/ /26	Sivert-Tehachapi		*25*	Entire line *to be replaced*	
4/ 7/28	Goshen Jct.-Fresno, Palmdale-Saugus, Caliente-Sivert		......	......	Still very active
4/14/28	San Luis Obispo District	Cedar and redwood	......	......	Riddled from end to end
4/16/28	Colton		......	......	
4/24/28	Indio		......	......	
6/20/28	Elmore and Dunsmuir		......	......	
7/ 9/28	Leaf		......	......	Base of poles

TABLE 80—*(Concluded)*

Date	Location	Kind of wood	Age, years	Number attacked	Kind of termite and location of attack
7/12/28	Bryn Mawr, El Casco and Beaumont; also Strathearn-Burbank, Indio-Garnet, Los Angeles-Colton	Untreated white cedar			Bottoms, tops and crossarms
8/21/28	MP-606, near Indio	Cedar and fir	20	Nearly all	*Paraneotermes simplicicornis*
8/28/28	San Luis Obispo	Cedar			*Kalotermes minor*
8/28/28	Guadalupe	Cedar			*K. minor*
11/9-10/28	MP-594-606, Indio	White and red cedar			*Kalotermes* and *Reticulitermes*
11/29 to 12/ 2/28	Beaumont-Cabazon	Cedar		All badly damaged	*Reticulitermes*
11/30/28	San Jose	Cedar			*Zootermopsis*, *K. minor*?
11/29 to 12/ 2/28	Niland and east				*Reticulitermes*
1/23/29	San Luis Obispo	Cedar, butts			*K. minor*
2/ 8/29	Watsonville Jct.	Cedar	20	Throughout	*K. minor*
3/ 1/29	Carpenteria	Douglas fir crossarm	15		*K. minor*
3/ 2/29	MP-631. L. A. Division	Sawn redwood	23	1	*Paraneotermes simplicicornis*
3/ 6/29	Corvallis-Alpine Jct.		4		
3/11/29	Modesto		16		*Reticulitermes*—?
3/11/29	Niles				*Reticulitermes*—?
3/13/29	Goleta	Round redwood	22		*K. minor*
5/16/29	MP-153 Oakdale Branch	Sawn redwood			*R. hesperus*
6/ 8/29	Portland	Untreated	6		*R. hesperus* and *Zootermopsis*
10/25/29	Redding				*R. hesperus*
11/25/29	Mojave	Redwood stub			*R. hesperus*
2/28/30	MP-988-9 Nogales Branch		14		
3/27/30	Estrella	Redwood	25		*Amitermes*
8/20/30	Algoma	Butt-treated Douglas fir	4		*Zootermopsis*
10/29/30	West Oakland Yards	Douglas fir	15-20	Several	*Zootermopsis*, up to 15 feet above ground
2/25/31	Logan-Watsonville Jct.	Crossarms			
6/26/31	MP-646, 656, 657, Salt Lake Division	Cedar	15		*R. tibialis*
10/ 6/31	Gael, Ariz., Tucson Division	Douglas fir crossarm	22	Several	*Heterotermes*

TABLE 81

COST OF SIGNAL LINE RECONSTRUCTION, 1926–1933—ARRANGED GEOGRAPHICALLY, NORTH TO SOUTH

Item No.	Location	Year	Original line			New poles	Stubs	Cost
			Number of poles	Year	Type			
1	Eugene-Portland	1931	About 3,500	1907–22	(A number replaced in 1925)	112	......	$ 3,065
2	Yoncalla-Divide	1931	510	1907–10	Untreated cedar	360	......	6,799
3	Grants Pass-Hugo	1931	390	1923	Untreated cedar	......	75	509
4	Pryor-Springfield	1931	1,230	1926	Butt-treated Douglas fir (see Table 79, item 6)	570	161	9,404
5	State Line-Kirk	1931	1,650	1925/6	Butt-treated Douglas fir (see Table 79, item 6)	550	288	4,260
6	Gregory-Steinman	1930	250	1918–20	Untreated Douglas fir	150	100	5,155
7	Edgewood-Metcalf	1931	150	1918	Untreated Douglas fir	100	50	2,565
8	Mt. Shasta-Edgewood	1927	450	1915	White cedar and square redwood	325	100	6,278
9	Smithson-Dunsmuir	1930	510	1908	About 40% of original white cedar poles renewed 1918-20	260	......	7,380
10	Redding-Kennett	1926	500	1907	Cedar	400	......	9,810
11	Red Bluff-Cottonwood	1931	450	1906	White cedar and square redwood. All were stubbed in 1922. During 1932 and 1933 all remaining poles will be renewed	200	......	3,910
12	Lick-Gilroy	1929	650	1906	White cedar square redwood	540	......	4,700
	Gilroy-Watsonville Jct.	1929	495	1906				
13	Wright-Santa Cruz	1929	440	1916	White cedar	60	......	670
14	Vasona Jct.-Santa Cruz	1931	150	1912–16	White cedar	150	......	3,465
15	Spreckels Jct.-Santa Margarita	1927	3,000	1906–7	White cedar and square redwood	625	1,425	12,280
16	Santa Margarita-San Luis Obispo	1929	420	1901	Square redwood	100	......	2,900
17	San Luis Obispo-Gaviota	1931	2,436	1906	3/5 sawn redwood, balance western red cedar and round redwood	100	......	3,455
18	Gaviota-Santa Barbara	1929	981	1906	Ditto	560	90	5,986
19	Santa Barbara-Ventura	1931	650	1906	Cedar and redwood. 460 poles stubbed in 1923	100	100	2,115
	Santa Barbara-Ventura	1932	......	1906	Cedar and redwood	......	......	7,435

TABLE 81—*(Concluded)*

Item No.	Location	Year	Original line			New poles	Stubs	Cost
			Number of poles	Year	Type			
20	Burbank-Oxnard	1933	1,430	1906	Cedar and square redwood	350	....	$ 5,000
21	Sivert-Tehachapi	1926	780	1901	Square redwood	480	....	13,723
22	Tehachapi-Mojave	1931	520	1905-06	White cedar	260	....	6,100
23	Palmdale-Saugus	1929	940	1905-06-07	White cedar and some redwood	983	....	24,640
24	Alhambra-Colton	1933	1,326	1906-08	Cedar and square redwood	270	....	4,940
25	Garnet-Indio	1930	860	1908	White cedar and untreated Douglas fir	634	....	12,290
26	Niland-Knob	1930	1,450	1912	White cedar	267	....	2,940
27	Wellton-Estrella	1931	2,730	1911	White cedar and square redwood	375	....	11,140
	Totals	....	28,848	....		8,881	2,389	$182,914

Note.—These data show expenditures for 1925–1931 only. Considerable sums were expended in the interim, but no attempt has been made to show all such changes. One example may be given:

Items 17 and 18, San Luis Obispo to Santa Barbara: original construction 1906, 2,063 sawn redwood poles, 1,354 round poles, principally western red cedar, some redwood.

Subsequent repairs:	
1913, 1,200 stubs	$1,900
1921, 900 stubs, 300 new poles	4,420
1922, 75 new poles	1,590
1924, 780 stubs, 10 new poles	3,060
1929, 90 stubs, 660 new poles	5,986
1931, 100 new poles	3,455

TABLE 82

List of principal cases of termite damage to railroad structures and bridges—reported to the Subcommittee on Building and Railroad Structures

Structure	Termite species	Description of damage	Repair methods and cost
SP 696-F Swiss Home, Ore.	*Zootermopsis angusticollis*	17-year-old fir piling considerably damaged, and decayed all the way through. 7-year-old cedar piling, sap decayed, termites in sound heartwood	Cedar piles hewed off and painted with hot creosote; $35. Fir piles renewed with creosoted piling
763-A SP Coos Bay Branch	*Zootermopsis*	Cedar piling	Sapwood removed, heart painted with hot creosote; $10
SP Coos Bay Branch	*Zootermopsis angusticollis*	Port Orford cedar ties: ". . . a considerable number of the older ties for about ¾ mile. Burrows extend half way to tops of ties"	Replaced with creosoted ties
744-C SP Coos Bay Branch	*Zootermopsis*	Cedar piling	Entire trestle renewed with creosoted fir
Pryor SP Cascade Line	*Zootermopsis angusticollis*	Untreated cedar and fir ties, and fir ties treated with zinc chloride, damaged; many to the extent that replacements were necessary	Replaced with creosoted fir ties
712-D Mill City Branch, Ore.	*Zootermopsis*	Cedar piling	Cut off down to sound wood; spliced with creosoted stubs; $30.
Dunsmuir		Lineman injured when a pole fell; it was found to be honeycombed at base by termites	Replaced with creosoted pole
Loleta NWP MP 270	*Zootermopsis angusticollis*	6-year-old redwood piling badly damaged by termites and decay	Replaced with concrete
SP Station Sacramento	*Reticulitermes hesperus*	Termites came through cracks in foundation and damaged records in fireproof vault	Cracks plastered up, ground cleaned up and distillate poured around foundations
Cordelia, Calif. SP 41-A	*Reticulitermes hesperus*	32-year-old creosoted fir pile; damaged by termites entering through crack to heartwood	Replaced with creosoted pile; $32

TABLE 82—*(Continued)*

Structure	Termite species	Description of damage	Repair methods and cost
SP 288-E near Red Bluff	*Reticulitermes hesperus*	Termites caused extensive damage to untreated fir sway braces, girts, and redwood bulkhead	Renewed with creosoted fir
SP 255-E near Redding	*Reticulitermes hesperus*	30-year-old creosoted fir pile damaged	Infested portion removed and creosoted post installed; $5
SP 316-H, near Dunsmuir	*Reticulitermes hesperus*	Untreated fir caps and stringers infested	Replaced; $58.35
SP 210-A near Chico		Cedar piles, 10 and 13 years old; termites and decay together	
SP 372-H near Susanville	*Zootermopsis nevadensis*	Centers of 2 untreated fir piles 18 years old, rotten and honeycombed by termites	Cut off below ground line, creosote poured on top, and redwood post painted with creosote placed on top; $52
SP 42-I near Napa	*Zootermopsis angusticollis*	Of 20 redwood piles driven 1908, 9 were replaced prior to 1930 and 4 of the rest found to be decayed and badly infested with termites	Cut off below ground line and redwood posts spliced on
SP, West Oakland Yard	*Zootermopsis angusticollis*	Store 4: Untreated fir caps and joists badly damaged by termites and rot. Creosoted fir piles cut off too close to ground line decayed inside, but creosoted shell surrounding decayed center sound and supporting the building	Caps and joists replaced with fir painted with creosote
SP, West Oakland Yard	*Zootermopsis angusticollis*	Machine Shop: Redwood sills and joists and fir posts, stringers, and floor badly damaged. Posts and floor last about 3 years; redwood sills and joists about 10 years	Replaced with same materials
SP, West Oakland Yard	*Zootermopsis angusticollis*	Untreated fir pole, 15 or 20 years old: *Zootermopsis* found to a height of 15 feet above ground	Replaced with creosoted pole
SP, Oakland Pier	*Zootermopsis angusticollis*	Redwood sills and fir joists damaged where they made contact with each other	Replaced with creosoted fir
Richmond Belt Ry.	*Reticulitermes hesperus*	9-year-old untreated fir switch ties and cedar cross ties damaged	Replaced with creosoted ties

TABLE 82—*(Concluded)*

Structure	Termite species	Description of damage	Repair methods and cost
Richmond Belt Ry.	*Zootermopsis angusticollis*	Water tank on creosoted fir tower with redwood braces. Fir timbers framed after treatment; termites attacked untreated centers; also redwood braces	Replaced with creosoted fir, framed before treatment
Pole line, Chittenden to Gilroy	*Reticulitermes hesperus* and *Kalotermes minor*	Redwood poles, about 300, installed 1906. Now nearly all stubbed and about ¾ attacked by *Reticulitermes* or *Kalotermes*, or both	
SP Station Naples, Calif.	*Zootermopsis angusticollis*	Damage to redwood and fir base boards and to fir siding	Replaced
SP 459-A, near Los Angeles	*Reticulitermes hesperus*	2 untreated fir bulkhead planks infested	Replaced; cost of labor, $15.72; material, $5.00
SP 464-B, near Los Angeles	*Reticulitermes hesperus*	8x17 untreated fir wing cap infested	Replaced; cost of labor, $12.12; material, $4.00
SP 502-A, Long Beach Branch	*Reticulitermes hesperus*	Cap, sub-cap and four stringers infested	Replaced; cost of labor, $92.78; material, $25.00
Monorail crane, Wilmington	*Kalotermes minor* and *Zootermopsis angusticollis*	688 cedar piles, driven 1923-24. In 1930, 15 were found to be infested with *Kalotermes* and 2 with *Zootermopsis*. The sapwood of all piles was decayed	All piles were repaired according to extent of damage, as follows: 6 spliced with creosoted fir; 11 sapwood removed and all termite damage cut out, then concrete pier poured around heartwood. On piles not damaged by termites decayed sapwood was removed to about 3 feet below ground line and heartwood painted with hot creosote up to cap about 3 feet above ground. Cost of 11 concrete piers, $6 for labor and $1.07 for material per pile
Santa Fe E-263 Linda Vista	*Kalotermes minor* and *Reticulitermes hesperus*	Untreated hemlock framed bent, 11 years old, badly damaged by termites and decay	Renewed with creosoted Douglas fir; total cost, $555.23
Southern Pacific-Santa Fe Union Station, Phoenix Ariz.	*Heterotermes aureus*	8-year-old oak interior trim eaten out, oak panelings in back of radiators honeycombed, door and window casings also attacked	Entire panels removed and replaced with stucco on the exterior and tile base and plaster on the interior, both applied against metal lath on steel studs. New window sills and sashes installed. Cost of labor and material, $187.00

Bridge 93-C S D & A Ry.	(a)	Wing brace decayed.
	(b)	Wing brace renewed with redwood, ground and timber treated with creosote.
	(c)	Cost to repair, $18.00.
Bridge 13-B S D & A Ry.	(a)	Three piles attacked by termites.
	(b)	Treated by forcing arsenic sulfate into piles under pressure.
	(c)	Cost to repair, $5.00.
Bridge 9, Lakeside S D & A Ry.	(a)	Bulkhead and braces decayed and infested with termites.
	(b)	Bulkhead and braces renewed, ground and timbers treated with creosote.
	(c)	Cost to repair, $80.00.
Bridge 16, Lakeside S D & A Ry.	(a)	Mud blocks, one cap, and 3 stringers infested with termites.
	(b)	Bridge retired on account of change in drainage.

II. Bridges and Railroad Structures

HISTORICAL AND ECONOMIC ASPECTS

There seems to be no reason to doubt that termites have been attacking bridges ever since bridges were first built in termite-infested territory; but since they have not been recognized as such and reported separately from decay, it is not possible even to estimate the damage done by termites prior to the activities of the Termite Investigations Committee.

Of the thousands of reports of termite damage made to the Committee, the number reporting attacks to bridges and other railroad structures was only about forty—perhaps 1 per cent. In the majority of these few cases the damage was not sufficient to necessitate immediate or extensive repairs. In the appended table, the costs of some of these repairs are given; the total is less than a thousand dollars. Undoubtedly the actual damage by termites in connection with decay was much more than this. So far as bridges are concerned, damage by termites and decay cannot well be separated, and the observations and recommendations given are from the standpoint of preventing both kinds of damage.

INSPECTION

It is apparent that any system of inspection having for its object the discovery of timber decay and structural weakness, will determine the existence of termite attack in its early stages. Such a system, as practiced on one of the western railroads, provides that on each division there be a bridge inspector who will make four regular inspections a year, upon which current or emergency repairs are based. Cooperating with the division inspector is a general bridge inspector, working under the jurisdiction of the bridge engineer of the central office, who participates with the division engineer, bridge and building supervisor and bridge inspector in the fourth, or annual, inspection. A complete record of this last inspection in due course of time is furnished to the engineering officer in charge of maintenance, and upon this the yearly bridge construction and repair program is formulated.

Some such system followed up with the essential precautionary measures is recommended as a proper and safe method of protecting wooden structures against termite attack.

PREVENTION OF TERMITE DAMAGE

Termite damage to bridges, as implied above, is not considered a serious problem. It is not difficult to find the reason for this, because, as stated in the General Recommendations of the Committee (chap. 46), good construction will largely eliminate danger of termite damage. Bridges are usually well built, because they must be so built as to carry their loads for long periods of time. For so-called permanent construction, concrete or masonry is used. Two factors enter which make it inadvisable to use such long-lived and expensive construction: first, it is usually desirable to keep capital outlays to the minimum consistent with good construction; second, the anticipated economic life of the structure may be less than the physical life of the permanent types of construction. Timber construction is then indicated, because of the low first cost and ease of repairs.

All species of wood are subject to the attacks of termites and to decay, but in greatly varying degrees. Unfortunately, the naturally durable woods are by no means the most common, and most woods must be treated with preservatives if they are to resist such attacks. Whether treated wood, naturally durable wood, or untreated ordinary wood should be used depends on the liability to attack in the location where used, the life expected, and, of course, the permissible capital outlay. There are given below some observations which, it is hoped, will be of service as a guide to users of timber.

PILING AND TIMBER IN CONTACT WITH THE GROUND, OR IN LOCATIONS WHERE CONTINUOUSLY DAMP

These are the conditions hardest on timber, as they are most conducive to the activities of *Reticulitermes* and *Zootermopsis*, as well as being most favorable to decay. Untreated pine, fir, or any commercially available species of untreated wood other than redwood, cypress or cedar should not be expected to last more than a few years. Creosoted timber is usually used where the longest possible life is expected. It is not possible to give exact figures as to the life which may be expected, but some indications can be had from the following:

Redwood. A study of the records of bridges on several hundred miles of the Southern Pacific Lines in central California gave the following:

Average age of 1,940 redwood piles now in service	40.2 years
Average service rendered by 915 redwood piles in the same lines which have failed and been replaced	34.0 years
Average life of 66 redwood box culverts in the same lines which have failed and been replaced	26.9 years

It will be noted that the box culverts, made of sawn lumber, were less durable than the round piling. This may be accounted for by the observation that the durability of redwood varies according to the conditions of growth; the dense, slowly grown wood near the butt of large trees, or the wood of trees grown under conditions of moisture promoting density and strength, is much more durable than the coarser wood from the tops of large trees or from quickly grown small trees. For this reason, redwood to be used in contact with the ground should be of a good grade, such as "Select All-Heart Structural," and free from sapwood.

Cedar. Data were not available to the writer for the computation of average life as given for redwood; but it may be said that there are large numbers of both Port Orford and western red cedar piles which have been in service in Oregon 30 to 40 years, and are still sound. It is generally considered that the durability of good cedar of these species is about equal to that of comparable redwood.

In the case of both of these woods, some failures have been reported after very short service. These can usually be traced to the presence of sapwood, which is not termite-resistant nor decay-resistant, to the use of rapid growth timber or to the use of poor grades of lumber, and prove nothing except that there is need for intelligence and experience in the interpretation of the phrase "durable timber."

Creosoted timber.—Pressure-creosoted Douglas fir properly handled after treatment, is very satisfactory as a structural material. It is not possible to make an accurate estimate of its life, because it has not been used long enough on the Pacific Coast. The Southern Pacific Company has been using pressure-creosoted Douglas fir piling and timber extensively for 42 years, and the replacements to date are, statistically speaking, negligible. Where failures have occurred, they have usually been due to breaking of the creosoted shell after treatment, or to mechanical failures due to overloading, etc. One point cannot be stressed too strongly or repeated too often; creosoted timbers must not be cut after treatment, as the smallest break in the creosoted shell affords an entrance to wood destroying organisms. This was strikingly brought out in the report of the San Francisco Bay Marine Piling Committee, which found that 85 per cent of the failures of creosoted piling were due to holes in the creosoted shell made by pike poles, "dogs," and by too severe driving. It is further illustrated by two reports of termite damage to creosoted fir piling. In both cases the interior had been eaten out, but the creosoted shell was intact. Entrance had been effected through cracks opened in driving.

SUPERSTRUCTURES AND OTHER LOCATIONS WELL ABOVE GROUND, USUALLY DRY

Here the danger from termites and decay is much less. While dry-wood termites *(Kalotermes)* are responsible for some damage to the upper parts of poles and buildings, they have done very little to bridges. Decay organisms must have moisture, and timber in locations continually dry (e.g., the upper parts of buildings and poles in dry climates) may be regarded as practically immune to decay. In bridges, even with open deck railroad construction, where the stringers are well separated, there are always some places where moisture may accumulate, but decay at such points is much less rapid than when the timbers are on or in the ground. Experience of the Southern Pacific Company indicates that untreated Douglas fir stringers in open deck trestles will give an average life of twelve to fifteen years. When decay occurs it is almost invariably at the points of contact between stringers and caps.

Untreated Ponderosa pine is seldom used for such purposes, as, due to the wide sap ring on pine trees, it is difficult to cut large timbers so that they contain heartwood only.

The durability of redwood and cedar is as advantageous here as in the locations more favorable to decay, but another factor assumes major importance. In the case of piling, posts, and caps, only the strength in compression is involved, and redwood and cedar are amply strong. Stringers must have, in addition, a high bending strength. Again, the ultimate choice depends largely on economic considerations. For greatest durability and strength in wooden structures, pressure-creosoted timber is used; on the Pacific Coast this means Douglas fir almost exclusively. For structures carrying smaller loads, as highway bridges, select all-heart structural redwood is widely used. The use of untreated fir timbers is decreasing rapidly, because it is usually more expensive in the long run.

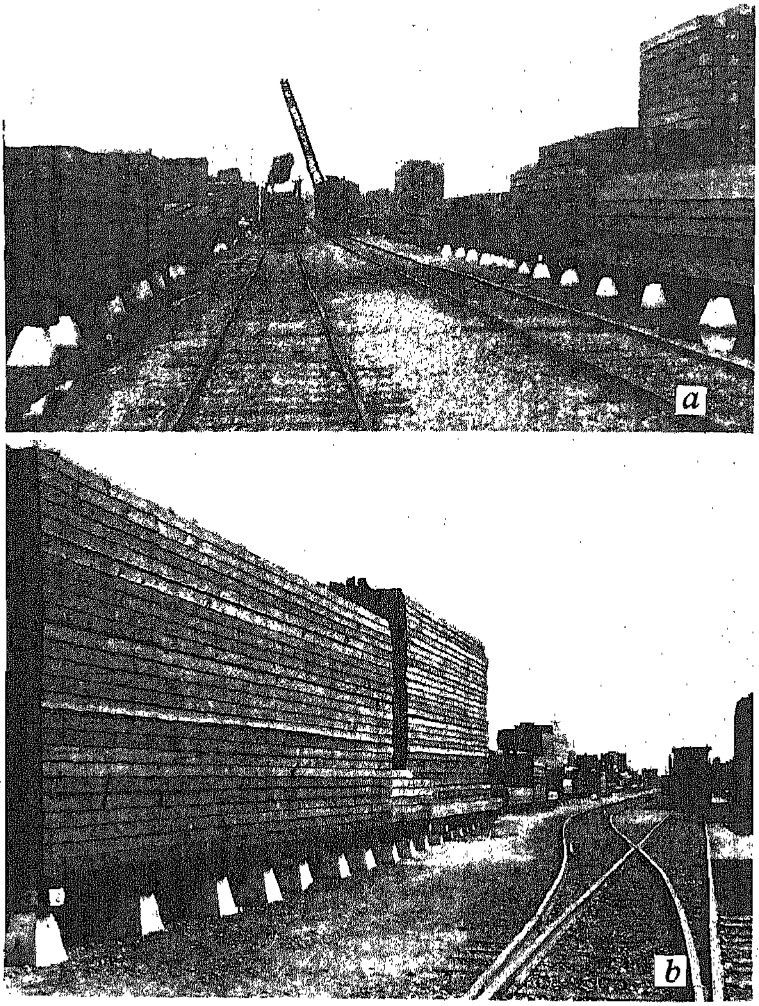

Fig. 177. *a* and *b*. Railroad bridge timbers in storage yards at Southern Pacific Company treating plant, Oakland, California.

There are some cases where creosoted timber cannot be used, because of its color, its odor, or the fact that it cannot be easily painted (chap. 37). Handrails on bridges are an example, and floors in cattle and refrigerator cars. Here properly selected grades of the naturally durable species may be used, or recourse may be had to any species treated with the various inorganic salts, such as zinc chloride, sodium fluoride-nitrophenol combinations, and Zinc-Meta-Arsenite (chaps. 33–35). None of these has been used extensively on the Pacific Coast. On the basis of experience in other regions, and considering the International Termite Exposure Tests now in progress, the three named may be expected to give good service, but only Z.M.A. has shown resistance to termites when in contact with the ground.

PROTECTION METHODS USED IN STORAGE OF STRUCTURAL TIMBER

Although the subject of lumber storage piles will be dealt with in another section of the report, we desire at this time to submit the photographs (fig. 177) showing the type of construction used in protecting structural timber from termite attack, as well as ground conditions. Note the footings upon which rest creosoted timber sills. These views were taken at the Southern Pacific Company's Oakland Yard, California.

REPAIR OF TERMITE DAMAGE

The general principle followed in making partial renewals of wooden structures is to use materials which will last as long as the remaining life of the rest of the structure. In the case of bridges, etc., as reported in Table 82, where it has appeared that the undamaged parts of the structure were in excellent condition, replacements have been made with material as good or better than the original material. This course is fully justified in the case of structures such as 228-E and 255-E, in the table, where the failure was, in a sense, accidental, in that the original creosoted piles were damaged in driving, and not due to inherent liability to failure of the original material.

The use of repair materials more permanent in nature than the original, as in the case of 372-H, in Table 82, is questionable, since, if this course is followed consistently, the structure will ultimately be better, through replacements of all original parts, than it was in the first place. This may be justifiable if the expected economic life is great, but the cost of such piecemeal renewals is undoubtedly greater than complete rebuilding. Sometimes, however, as in the case of the monorail crane, this is the only feasible course. Here complete rebuilding of the structure would have been very expensive, and was not necessary, as the large majority of the original piles were still capable of carrying their loads, and protection was all that was required.

The cases of damage considered in this section have been chosen from many thousands of inspection reports in the files of the Southern Pacific Company showing conditions varying from no termite infestation to very severe infestation.

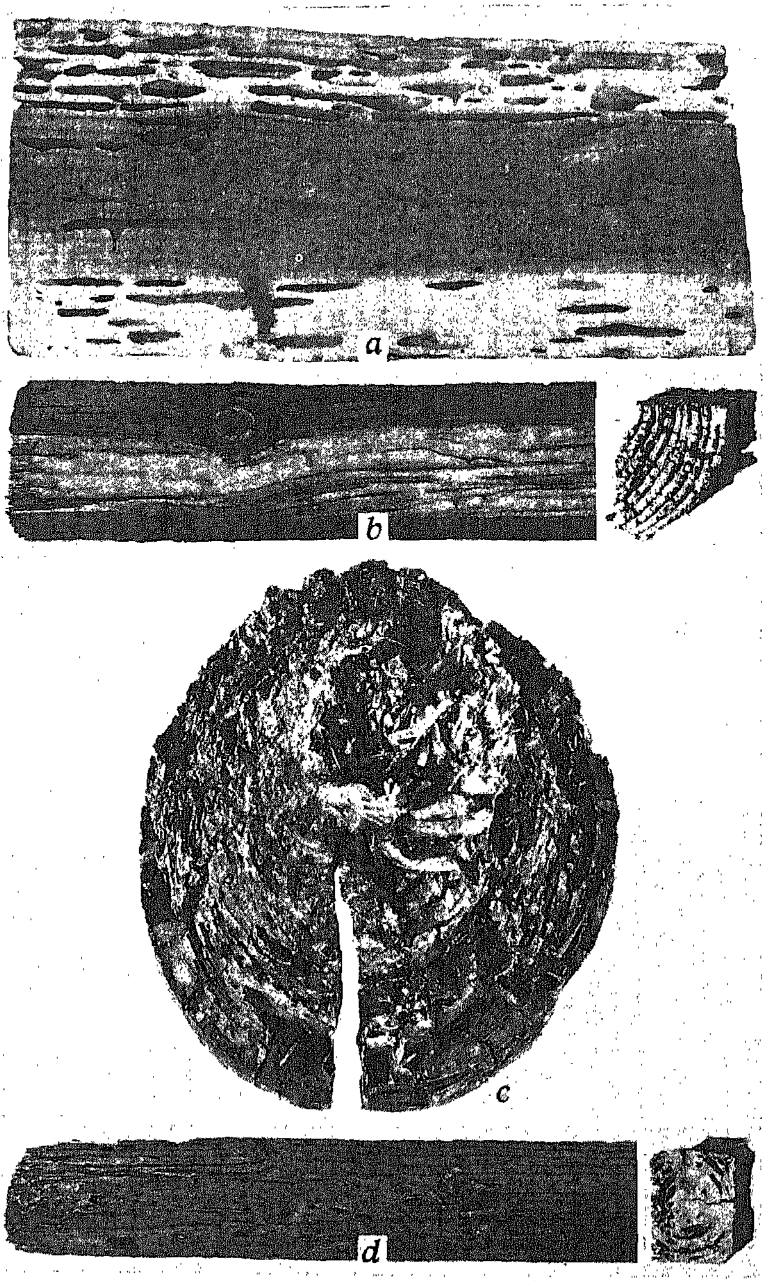

Fig. 178. *a*. Section of a round redwood signal pole, located about four miles north of Santa Barbara, California, on the Coast Division. This section was taken 8 feet above ground. The entire pole was similarly infested by the common dry-wood termite, *Kalotermes minor*. Age of pole, about 22 years. Sample was taken in March, 1929.

Table 82 lists some, but not all, of the cases of attack on structures which have been reported to the Committee. Those have been included about which enough is known to be instructive from the standpoint of prevention and repair methods. Those omitted were indefinite, or of value only as indicating the distribution of termites, hence of interest primarily to the Subcommittee on Biology.

Most of the cases of damage to untreated wood occurred in pieces of timber where both sapwood and heartwood were present. It is a well established fact that termites, as well as fungus growths which cause decay, will readily attack sapwood of any species. It is probable that much of the termite damage reported herein would not have occurred if the wood had been all heartwood.

(Fig. 178.—Concluded)

b. Longitudinal view and cross section of an untreated Douglas fir crossarm near Gael, Arizona, which was almost totally destroyed by the subterranean termite, *Heterotermes aureus.* Many other poles were found to be in a similar condition and were recently replaced. Age 22 years. Photographed in October, 1931. *c.* Full section of a creosote butt-treated Douglas fir pole almost completely eaten by termites. This view was taken early in 1931 near Midland, Oregon. Over 50 per cent of the entire line was replaced in 1931 (see Table 79, item 6). *d.* Longitudinal view and cross section of an untreated Douglas fir crossarm taken from a white cedar pole at mile post 268 near Oceano, California, on the Coast Division. Damage was caused by the common dry-wood termite, *Kalotermes minor.* Age of pole line, 24 years. Photographed early in 1931.

CHAPTER 52

MISCELLANEOUS EXPOSED STRUCTURES

BY

A. C. HORNER AND GEORGE A. RADER

WHARVES AND DOCKS

Although it was thought in 1928 that termite damage to wharves and docks and appurtenant structures might constitute a problem of sufficient importance to warrant special investigations, the record of damage to such structures is remarkably small. Few cases of damage by damp-wood termites have been reported to the Committee. In one case the infestation was the cause of structural weakness in a timber. Some cases of damage are cited. An untreated piling twenty-seven years old at Lebanon, Oregon, was attacked two feet below and seven feet above ground. Untreated piling set in water at Port Costa, California, was attacked. In a pier at San Francisco, California, untreated piling, wharf timbers, and the shed covering the wharf were so badly infested that they had to be removed. At Coos Bay, Oregon, an untreated pile seventeen years old and another seven years old were attacked. Both piles were damp. The attack extended from two feet above ground to about eighteen inches below ground.

There is little danger of damage to wharves by subterranean termites except at the land end of the structures. No damage has been reported from dry-wood termites. This is probably due to the absence of nearby sources of infestation.

Methods of prevention and repair of termite damage for wharves and docks are the same as the methods recommended for bridges and railroad structures (chap. 51) and buildings (chap. 48).

OIL DERRICKS AND OTHER WOOD TOWERS

HISTORY OF DAMAGE

The number of cases coming to the attention of the Committee, of termite damage to oil derricks, wood water tank towers, observation towers, and other structures of a similar nature has been very small in comparison with the number of such structures. The only instances of damage which are numerous enough to warrant specific mention were reported as a result of a questionnaire sent out by the Committee to major oil-producing companies in California. Several of the cases of damage reported as a result of this questionnaire were investigated by Committee fieldmen.

An understanding of the use to which oil derricks are subjected is a prerequisite to a proper conception of the relation between the construction of oil derricks and termite attack. Oil derricks normally are used for a period of six months or so for drilling the well and thereafter are used infrequently, if at all, for work which does not usually require the entire strength capacity of the derrick. As a consequence most oil derricks receive but little attention in the way of inspection or maintenance and the activities of termites can proceed more or less undisturbed.

Termite damage to wooden oil derricks in California was first noted in 1923. Little attention was paid to the subject until 1928, at which time the oil companies cooperating with the Termite Investigations Committee made a fairly comprehensive survey of conditions in various fields both in the vicinity of Bakersfield and in southern California. An inspection of 147 derricks located in southern California disclosed that 59 per cent of them were infested with either dry-wood or subterranean termites. Both types of termite were frequently found in the same structure, and dry rot was associated with the subterranean termites in 37 per cent of the derricks inspected. These inspections were made at representative points throughout what were believed to be the most heavily infested oil field districts, and should not be understood to be representative of the degree of infestation that may exist in the more than 10,000 wooden oil derricks in California. The observations of Committee fieldmen and an evaluation of the reports from the major oil companies gave rise to the opinion that termites and dry rot do not present a particularly serious problem so far as derricks are concerned. The infestations reported were not segregated as to subterranean and dry-wood termites and no information is available as to the relative activities of the two types.

The following excerpts are taken from reports to the Committee in reply to questionnaires sent to various oil companies.

> Derricks in the southern part of the State were found attacked from top to bottom—including foundation members. Possibly the worst damaged portions were the crown blocks, water tables, and sills and legs at the corners. Portions of derricks were replaced, repairs made to adjacent buildings, one being abandoned and a few derricks were totally replaced. In one field, 49 derricks out of 87 examined (56 per cent) were infested in varying degrees, while on one of our leases 21 derricks out of 30 examined (70 per cent) were infested. The dry-wood species predominates in these particular fields. The age of the derricks varies from 9 to 20 years. It is hard to estimate the annual damage attributed to termites, but during the past 2½ years we have spent about $12,000 for repairs in southern California, most of which was made necessary by the destructive work of termites.
>
> Termite infestations have been found in derricks, houses, power and telephone poles, wooden braces and posts in pumping (Jack) plants, culverts, bulkheads and fences in every location in our fields. The infestations were found in Douglas fir, redwood, white spruce, red cedar and eucalyptus woods which had been in service longer than five years. Of the total of 362 wooden derricks of our Company located in Los Angeles Basin, slight infestation was found in 90 per cent; partial infestation of footings and sills in 40 per cent; and infestation from top to bottom in 20 per cent of the derricks. We have no basis for estimating the monetary value of the total damage due, respectively, to termites and/or dry rot. However, in southern California we have estimated the cost of repairs that should be made to wooden derricks, due to termites and/or dry rot, would require an expenditure of $8,830.

While the sum total of information on derrick and tower structures collected by the Committee has been small, it is believed that it presents a reasonably good idea of the relative importance of the damage done to oil derricks and similar structures as compared to damage done to other types of structures.

METHODS OF PREVENTING AND REPAIRING DAMAGE

The problem of termite damage control in the wood tower or oil derrick type of structure is not greatly different from that previously discussed under Buildings (chap. 48) in so far as subterranean termites are concerned. Where untreated wood is in contact with termite infested soil termite damage may be expected. The obvious control method for the tower type of structure is to use treated wood or concrete for foundations of the tower. Sound heart grades of the naturally resistant species of wood, a comparatively light pressure treatment with coal-tar creosote or, possibly, some of the effective types of ground treatments (chap. 40) should be satisfactory for foundation purposes from the standpoint of subterranean termite damage prevention. The removal of all stumps, vegetation and casual wood from the site of the structure will be of assistance. Adequate drainage of the site is also recommended. Concrete form boards should be removed when concrete is used for foundation purposes. Regular inspection of foundation conditions to see that there is no earth in contact with the wood is highly important.

The problem of protecting these structures from dry-wood termite damage is not so simple. There are a number of chemicals and other materials, which, when applied to wood by pressure impregnation will render it reasonably safe from dry-wood termite infestation (chaps. 33–35). Some of these materials when applied by the open-tank treatment would no doubt afford adequate protection. The mere spraying on of such materials, however, cannot be expected to afford more than very temporary protection. Perhaps the most important recommendation is to investigate nearby sources of possible infestation, such as tree stumps, pole lines, and any wood structure extending for some distance above ground, and to eradicate by the poison dust treatment any colonies found therein (chap. 38).

When derricks or towers are found to be infested with the dry-wood termite either the poison dust treatment or the poison liquid treatment will probably be found to be the most economical method of eradicating the colonies.

CHAPTER 53

LUMBER STORAGE PILES

I. RECOMMENDATIONS FOR PREVENTING AND REPAIRING DAMAGE

BY

A. C. HORNER AND EARL E. BOWE

INTRODUCTION

Reports made to the Committee indicate that in California termite damage to lumber storage piles, lumber yards, and shipments of lumber is caused chiefly by infestations of swarming dry-wood termites, *Kalotermes* (chap. 20). Some cases of damage by the subterranean termite, *Reticulitermes,* have also been reported, as well as a few by the damp-wood termite, *Zootermopsis.*

In the Hawaiian Islands, it is reported, termite damage by *Coptotermes* occasionally occurred in lumber stored in retail lumber yards. Comparatively inexpensive preventive measures, such as the use of cement blocks one to two feet in height under the supporting timbers, and the prompt extermination of termite nests, have been so effective that today termite damage is negligible in lumber yards and storage piles.

After a survey of the problem, the Subcommittee on Lumber Yards and Producers has reached the following conclusions: (1) The total damage done by termites to lumber between the lumber mill and the point of use is relatively very small. (2) "Good housekeeping" affords the means of preventing, at small cost, all termite damage except that occasioned by swarming dry-wood termites. It cannot be too strongly emphasized that there exists potential danger of widespread termite damage in lumber yards and elsewhere unless sanitary conditions are maintained. Cleanliness and orderliness in the lumber yard discourage the breeding of termites and will materially reduce, if not practically eliminate, the danger of termite attack. (3) Further trial of experimental methods recommended herein for preventing damage by swarming dry-wood termites will ultimately result in the efficient and economical control of this part of the problem.

RECOMMENDATIONS FOR PROTECTING LUMBER STORAGE PILES FROM TERMITE DAMAGE

No methods for eliminating termite hazard can be successfully carried out without a knowledge of termites and their habits. Since damage to stored lumber is caused chiefly by the dry-wood termite, *Kalotermes,* and to a lesser degree by the subterranean termite, *Reticulitermes,* it is essential to be able to distinguish these two types. One point of difference between them is their size, *Reticulitermes* being the smaller of the two. *Reticulitermes* is usually found near the ground, and builds runways from the ground to the wood, or in wood in contact with the ground, and leaves an earthy frass in its subterranean runways. *Kalotermes,* on the other hand, builds its runways in dry wood, in which it deposits pellets.

Make a survey of all lumber storage piles in the yard, and of the area within several hundred feet of the lumber, including all structures, dead parts of trees, tree stumps, poles, posts, etc. See that the following precautions are observed:

SUBTERRANEAN TERMITES

The ground should be kept dry by providing adequate drainage. *Reticulitermes,* the subterranean termite, requires moisture. The drier the ground, the less likely the presence of termites.

The foundations of lumber piles often provide a convenient passageway for the subterranean termite from ground to lumber pile and back again. They should therefore be of concrete or of wood made toxic to termites by impregnation with a sufficient quantity of proper chemicals (chap. 34). A species of wood which is naturally less palatable to termites (chaps. 41, 46) may be used when the conditions of service and the expected use-life of the foundations warrant it. Arrange the foundations so that the bottom of each lumber pile will be at least 12 inches, preferably more, above the ground. In Hawaii, it has been reported to the Committee, termite shields of metal placed above concrete foundations have given much increased protection against subterranean termites.

Fences, posts, and poles in and near lumber yards are a frequent source of infestation by the subterranean termite. Examine for termites by digging down a few inches below the ground alongside the posts. Keep all wood at least 6 inches from the ground, unless such wood is of the naturally durable species, or has been treated with a preservative. Make periodic inspections at least every six months to see that these structures are not infested.

Buildings and similar structures should be protected by keeping all wood at least 12 inches above the ground. Where this is not feasible, use wood made toxic to termites by impregnation with chemicals.

As a breeding place for subterranean termites the odds and ends of lumber, accumulations of paper, decayed vegetation, and other débris cannot be improved upon. Therefore, a general clean-up of all débris around piles of lumber is strongly recommended. Such measures will also pay dividends in preventing fungus growth with its consequent dry rot, in reducing fire hazards, and in promoting circulation of air for seasoning.

Watch for subterranean termites in the vicinity of lumber piles by driving sapwood stakes measuring 1 inch x 2 inches two feet in the ground; remove after three to six weeks, and examine for termite galleries. If there is no evidence of termite damage in any of the stakes, you may be reasonably sure that there are no subterranean termites in the nearby earth.

Unless lumber has been piled for several months, it is not liable to become infested with subterranean termites, and particularly not if the precautions described above are taken. If, however, infestations are found, they will usually be in only a few of the bottom pieces of the pile. These should be removed and exposed to sunlight and air for several days in order to kill the termites.

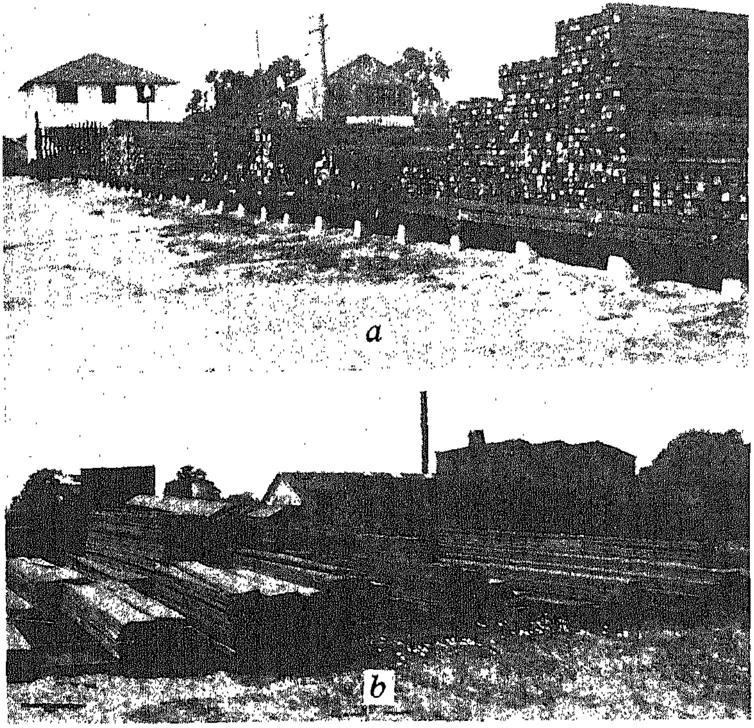

Fig. 179. Foundations for lumber storage piles. *a*. Good construction, good maintenance. *b*. Poor construction, poor maintenance.

Dry-Wood Termites

Dry-wood termites are more difficult to detect, but they are not likely to be troublesome in lumber piles except in the swarming season, and then generally only in lumber piled in the open air. Reports made to the Committee indicate that lumber piled in sheds or other closed buildings is seldom attacked by swarming *Kalotermes*. Infestations by this termite are most liable to occur during the swarming season, namely, the months of September, October, and November. They can be located by the small entrance holes, about the size of BB shot (fig. 73*a–b*) which the mated pairs make in the wood and then seal up. To protect lumber piles, examine for the dry-wood termite all dead tree stumps, dead portions of living trees, old buildings, fences, poles, etc., on or near the premises, particularly on the side from which the prevailing winds come. If infestations are found, they should be treated as indicated in chapters 38 and 46.

It is believed that one thorough spraying of the lumber piles with a solution of sodium fluosilicate will reduce infestation by the swarming dry-wood termite. Use 1 pound of sodium fluosilicate to 10 gallons of water and spray liberally on the top and sides of all lumber piles. It must be added, however, that the spraying of lumber piles is still in an experimental stage. The protection afforded to large piles of lumber will depend on the thoroughness of the spraying, especially between the pieces. Swarming termites prefer to enter piles between two pieces of lumber rather than at the sides, top or bottom of an individual piece.

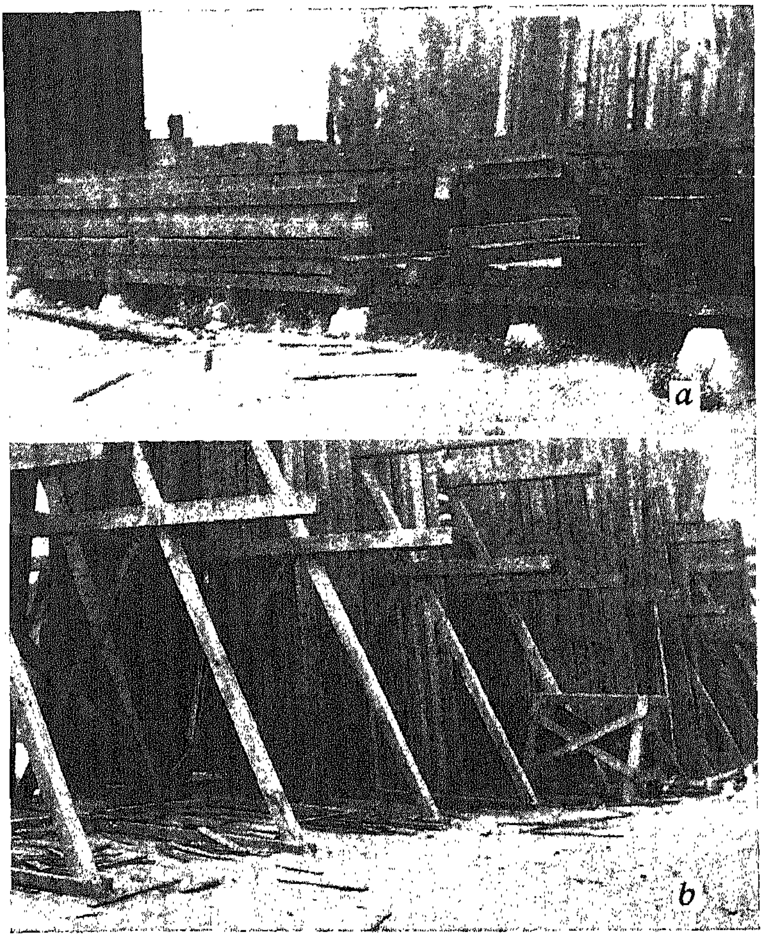

Fig. 180. Foundations for lumber storage piles. *a*. Good construction, poor maintenance. *b*. Fair construction, poor maintenance.

Laboratory experiments have also shown that dipping wood in a solution of sodium fluosilicate for 10 seconds gives complete protection against swarming dry-wood termites if the wood is kept dry.

If lumber in piles becomes infested with dry-wood termites, there are two methods of destroying the insects. One way is to introduce a small amount of kerosene into each hole made by the termites. Kerosene will penetrate the plugs with which the holes are sealed, and will enter the termite galleries in sufficient quantities to kill the termites.

The second method of destroying dry-wood termites in the wood consists of the use of a dry kiln or other enclosed space. Pieces of wood 2 inches or less thick should be subjected to a heat of 50° to 65° C. (125° to 150° F.) for a period long enough to raise the temperature in the center of each piece to 50° C. Termites exposed to a temperature of 50° C. in the laboratory of the University of California died after one minute of exposure. The length of time necessary to bring the temperature of the lumber to 50° C. throughout will vary with the condition of the wood. It is believed that two hours per inch thickness of lumber will be sufficient in all cases.

Where neither of the above methods is feasible, each piece of infested lumber may be marked with chalk at the termite holes and the infested sections cut out and burned. However, unless there actually are holes in the lumber, either open or plugged up by the termites, it is safe to assume that the wood is not infested.

If the lumber piles have been infested by swarming dry-wood termites, and if the swarming season is not yet over, further infestations may be expected. Therefore, as soon as possible after infestation is found, the lumber piles should be sprayed with sodium fluosilicate, as directed above. This spraying cannot be expected to kill termites already in the lumber, but it will be effective in preventing further infestation. Make frequent inspections during the swarming season. If swarming termites are seen in the vicinity of the lumber piles, trace them to their source, if possible, and exterminate them.

II. EXPERIMENTAL STUDIES OF METHODS FOR THE PROTECTION OF NEW LUMBER FROM COLONIZING DRY-WOOD TERMITES

BY

O. L. WILLIAMS

New lumber in piles at the lumber yard, in transit to a building site, or in piles at a building site, is subject to infestation during the swarming season by colonizing pairs of the dry-wood termite, *Kalotermes minor*. An infestation of this kind is particularly insidious because of the fact that the lumber, containing potentially destructive colonies, may be built directly into a structure, with the possibility of serious damage resulting within a relatively short time. In meeting this problem of infestation by colonizing termites, the Termite Investigations Committee undertook to test various methods and chemicals for the treatment of wood, with the object of finding an effective and relatively inexpensive preventive measure. This involved finding, first, one or more effective chemicals for use in making lumber treatments, and second, effective methods of applying these chemicals.

It should be pointed out that the treatment of lumber by any of the methods described below will give only temporary protection against colonizing termites. It is not to be expected that any of the treatments suggested will render the lumber termite-proof under all conditions of use or for an extended period of time after the lumber has been incorporated into the structure.

Methods.—All of the tests were made in the laboratory, on small test pieces measuring 1 inch x 4 inches x 12 inches. The pieces were of green Douglas fir, dry Douglas fir, green redwood, dry redwood, and dry Ponderosa pine, each of these being used with all of the chemicals and with all of the methods of treatment. It will be noted that two of the woods were used in both the green and the dry condition; this was for the purpose of determining what, if any, was the influence of the moisture content of the samples upon the establishment of a protective film of toxic material. After treatment each block was cut in half, and twenty-five nymphs of *Kalotermes minor* placed in each half. The termites were placed upon the broad surface of the test piece, and covered with a Petri dish 9 cm. in diameter, the latter being sealed in place with paraffin. Observations were made daily in order to determine whether or not the toxic layer was penetrated, the rate at which the toxic layer was damaged when penetrated, and the rate at which the termites were killed.

Three methods of treating the test pieces were used: (1) dipping in a small vat of solution, (2) spraying a solution with a hand spray, and (3) dusting a moistened surface with a hand dust gun.

1. *Dipping.* In the dipping tests the following chemicals were used: (1) sodium carbonate, 7 per cent; (2) sodium bicarbonate, 7 per cent; (3) borax, 1 per cent, 2.8 per cent, 10 per cent; (4) sodium fluoride, 2 per cent; (5)

barium chloride, 5 per cent; (6) sodium arsenite, 0.5 per cent, 1 per cent; (7) zinc chloride, 5 per cent; (8) sodium fluosilicate, 0.65 per cent, 2 per cent; (9) ethyl mercuric chloride, 4 per cent; (10) ethyl mercuric chloride-phosphate mixture, 4 per cent. The test pieces were completely immersed in these solutions for periods of from 1 second to 2 minutes, and at temperatures of from 18° to 90° C. They were then dried for several days before the termites were applied.

2. *Spraying.* The results of the dipping tests were obtained before beginning the spraying tests. Inasmuch as these tests indicated that sodium fluosilicate was best adapted for commercial use in establishing a protective layer of toxic material on wood, this chemical alone was used in the spraying tests. An ordinary hand spray was used in applying the solution. Three sets of tests were made; the first consisted of a single spraying treatment; in the second set of tests two spraying applications were made on successive days; and in the third set three spraying applications were made on three successive days. The elapsing interval between spraying allowed for thorough drying. A 0.65 per cent solution of sodium fluosilicate was used, this being a saturated solution at 20° C., the temperature at which the tests were made. No attempt was made to measure the exact amount of spray used; as soon as a block appeared to be thoroughly wet all over the spraying was stopped. This method was used because it is the procedure which would be followed in actual practice. After the final spraying the blocks were dried, cut in half, and the termites applied.

3. *Dusting.* Sodium fluosilicate and borax were used in the dusting tests. The test pieces were first sprayed with water until wet all over, and then dusted. The dusts were applied with a small dust gun. Here, again, no attempt was made to measure the amount of chemical used, and it was found difficult to dust the pieces uniformly. After dusting and drying, the pieces were cut in half and termites introduced.

Results.—Dipping and spraying lumber show certain advantages over dusting as methods of providing a toxic layer for the prevention of colonization by termites. Both of these methods can be used with a smaller outlay of apparatus, with less expenditure of time, and with more uniform results than is possible with the dusting method. It was found that a considerable waste of chemicals resulted in the dusting operation, partly through loss during application, and partly through loss in handling the treated wood. Furthermore, it was found to be much more difficult to apply the dust evenly than to apply the same chemicals in solution. Some of the pieces were coated with more than the amount necessary to prevent the entrance of termites, while others were not sufficiently protected.

So far as economy of chemicals is concerned, the dipping method proved better than the spraying, because of the fact that the applications could be made more uniformly. In spraying there is waste, not only because part of the solution is lost during the operation, but also because more than the required amount is used in many instances. This was shown by the rapidity with which some of the colonies were killed as compared with others.

Of the ten chemicals used, sodium fluosilicate gave the best results, with the single exception of sodium arsenite, which is too poisonous to man to be used commercially. Sodium carbonate, sodium bicarbonate, borax, barium chloride, ethyl mercuric chloride, ethyl mercuric chloride-phosphate mixture, and zinc chloride all proved relatively non-toxic to the termites in the maximum concentrations in which they were used. Sodium fluoride gave good results in some of the experiments but failed in others, while sodium fluosilicate gave consistently good results when used either as a dip or as a spray. Used as a dip at 20° C., in a 0.65 per cent solution, sodium fluosilicate invariably prevented the entrance of termites if the dipping was for a period of two minutes, but failed in a few instances when the dipping was for only ten seconds. Used as a spray, sodium fluosilicate was effective in preventing the entrance of termites in every test after only a single spraying treatment. It is probable that more of the chemical is used in this method than in the dipping method, as the death rate proved to be more rapid.

Conclusions.—Both the dipping method and the spraying method may be used with considerable success in coating lumber with a protective toxic layer to prevent entrance by colonizing termites. More uniform applications of the chemical can be obtained with the dipping method, but less elaborate equipment is required for the spraying method. Sodium fluosilicate in saturated solution (0.65 per cent, cold water) is the only one of the chemicals tested which meets the requirements of high toxicity to insects and low toxicity to the higher animals and man, and is recommended for use in protecting new lumber against colonizing termites.

CHAPTER 54

LEGISLATIVE ACTION

I. MUNICIPAL LAWS

BY

EARL E. BOWE

The most effective work which has been attempted in the way of legislative action seems to have been the drafting of recommended provisions for inclusion in building codes, which was done by Dr. T. E. Snyder, Senior Entomologist, Bureau of Entomology, U. S. Department of Agriculture. Dr. Snyder's recommendations were submitted to the Pacific Coast Building Officials Conference in 1927 and were incorporated in the Uniform Building Code, which has since been adopted by 110 cities. Although these recommendations were not made a part of the mandatory provisions of this Code, they have undoubtedly influenced many cities in drawing up building regulations, and have provided information which has been of value to architects, contractors and owners.

Two cities in California have passed ordinances seeking to regulate the transportation of termite-infested materials. One city and two states have passed laws seeking to regulate and license persons engaged in repairing buildings damaged by termites. One of these states has recently repealed the law regulating such practice.

It is believed that intelligently prepared legislation, properly enforced, may be of much benefit in reducing the sum total of termite damage. On the other hand, it is felt that legislation resulting from hysteria induced by unwarranted propaganda may do considerable harm.

CITY ORDINANCES

Ordinances which have been adopted by municipalities in an endeavor to prevent termite damage may be classed as measures to regulate:

(1) Construction practices, including clean-up of premises (chap. 46).
(2) Transportation and storage of infested material.
(3) Licensing of persons engaged in the practice of repairing structures damaged by termites.

For the past few years the Bureau of Entomology of the United States Department of Agriculture has advocated termite provisions for building codes. Many cities have adopted these recommendations.

The following publications contain special termite provisions, either those of the Bureau of Entomology or similar ones:

Wood Construction, by D. F. Holtman
  National Committee on Wood Utilization, 1929.
Termites in Buildings, by T. E. Snyder
  U. S. Department of Agriculture, Leaflet 31, June, 1929.
Recommended Minimum Requirements for Small Dwelling Construction
  U. S. Department of Commerce.
Termite Damage Prevention
  National Lumber Manufacturers Association, 1929.
Building Code Recommended by the
  National Board of Fire Underwriters, 1931.
Uniform Building Code
  Pacific Coast Building Officials Conference, 1927, 1930.
Uniform Building Code
  Florida Building Officials Conference, 1930.
Building and Loan Construction Standards, by John M. Wyman
  American Building Association News, 1930.

The conclusions of the Executive Committee of the Termite Investigations Committee on building specifications and their application to statutory building laws are incorporated in proposed building specifications (pp. 549–551).

TRANSPORTATION AND STORAGE OF TERMITE-INFESTED MATERIAL

It has come to the Committee's attention that two cities have enacted regulations on the moving or storing of termite-infested material. In one city it is required that any material infested with termites shall be burned. This ordinance was enacted almost entirely for the purpose of preventing the use, as firewood, of discarded poles in which dry-wood termites are present.

In another city houses to be moved are inspected to learn if termites are present. When the structure is jacked up the building inspector determines the presence and extent of termite damage, if any. He then issues instructions for repairs or treatment. If a member is structurally weakened by termites he orders its removal; if the member is not structurally weakened it is left in place. When the building is removed to the new site it is placed on a foundation which conforms to the provisions of the building ordinance. Under such circumstances any live termites in the building, unless the dry-wood termite is present, will soon die for lack of sufficient moisture.

RECOMMENDED ORDINANCE ON TRANSPORTATION AND STORAGE OF TERMITE-INFESTED MATERIAL

It shall be unlawful to transport, remove, or demolish any structure or part thereof, any wood, lumber, poles, or other material infested with termites, except as follows:

> Such structure or materials may be transported to the city incinerator or other place approved by the building inspector, for burning.
>
> Such structure or materials may be transported or removed after the infested part or parts have been repaired in a manner approved by the building inspector.

LICENSING OF PERSONS ENGAGED IN THE PRACTICE OF REPAIRING STRUCTURES DAMAGED BY TERMITES

A city licensing act for the control of those who make a business of repairing structures damaged by termites and fungi is not recommended. Such an act, if a need for it can be shown, should properly be placed in state government hands. There are several reasons why a licensing measure should be a state act. Among these are the facts that (1) in order to obtain the most efficient results it is desirable to have a uniform licensing law over a large area; and (2) few cities have officers qualified to conduct proper examination of applicants.

Most building inspectors are familiar with the tendency to over-license with high fees. Especially is this true in metropolitan centers where one city feels it needs relief from the possible or actual influx of poor craftsmen from adjoining cities. Different standards or requirements for applicants are usually set up by each city.

It is not the best policy for an enforcement officer to also conduct an examination for applicants. This would be the case in most cities, since because of lack of funds the examining and enforcing officer would be the same person. Each city can, however, contribute a great deal to the work of decreasing both termite and fungus damage by adequately inspecting, through the building department, all repair jobs involving such damage.

Most building codes require that permits be obtained for any alteration or repairs to a building regardless of the cost of the work involved.

It is suggested that where no state licensing act exists, a fee of 1 per cent of the charges made to the building owner for repairs, with a minimum fee of two dollars, be required for each termite and fungus damage repair job, if a city wishes to keep a thorough check on damage done by these pests. This fee schedule should be adequate to enable a building department to make a thorough inspection of each job, even though repairs of the kind occasioned by termites or fungi often require more time for inspection than the usual type of inspection work.

II. STATE LAWS

BY

W. C. JACOBSEN and ASHLEY C. BROWNE

Two states, California and Louisiana, have enacted licensing laws for those who make a business of repairing structures damaged by termites. The California law was enacted in 1929 and repealed two years later. The Louisiana law became effective in 1930.

In California the law was interpreted to include termites in the class of insect pests, and the licensing of persons engaged in "eradicating insect pests" was subject to the regulations of each county agricultural commissioner. Eradicators, or "termite control operators" as they are called, were licensed for one-year periods. No license fee or other fees were required. County agricultural agents required reports of each job to be filed with them. Reports included cost of the work, chemicals used, general nature of the damage, and a statement as to whether or not fungus damage was present. Each applicant for a license was subjected to a written and oral examination which included questions on the biology of termites, pathology of fungi, chemicals and how used, construction methods, and business ethics. Applicants who successfully passed the various examinations and were granted licenses represented one-fifth to one-third of those examined.

The California law is believed to have been successful in curbing many ineffective and exorbitantly priced "cures." However, the act provided no fund for enforcement; hence, the number of jobs inspected was only a small percentage of those completed. Cooperation of most termite control operators and building inspectors with the county officers was excellent. The intelligent manner in which the meager law was handled by the county agricultural agents demonstrated the practicability of such a law, and at the same time there was indicated the advisability of having the licensing law uniform, at least within the state. This law was repealed in 1931 at the instance of county agricultural commissioners, who felt it was an undue burden on them inasmuch as funds were not appropriated for its enforcement. A proposed state law was introduced at the 1931 session of the California Legislature to take the place of the Act repealed at the instance of the county agricultural commissioners, but it failed of enactment for various reasons, one of them being the inability to agree on the department of the state government which should be charged with the enforcement of the Act.

PREVENTION OF TERMITE DAMAGE THROUGH LEGISLATIVE ACTION

LICENSING TERMITE CONTROL OPERATORS

The primary objective to be gained by a systematic licensing or certification of termite control operators is to provide a group of thoroughly capable, qualified individuals to assist in, or to undertake for property owners, the control or elimination of termite infestations in buildings, structures or structural materials which would otherwise be reduced appreciably in value by the continued presence of termite infestation. Such licensed or qualified operators are of two types: those who specifically undertake the work of ridding the premises or structure of termites, and those who serve in a consultative capacity to property owners, architects or builders for the purpose either of preventing an incursion of termites or of prescribing for their riddance.

Protection against poor or unsatisfactory work of this nature is a basic need. There are those who would take advantage of a publicized pest by posing as qualified persons, even though they be incapable, through lack of basic training and understanding of the problem. Favorable circumstances, abetted by fear of property loss, would give unscrupulous individuals a chance to ply profitable trade without obtaining sound results.

The regulation of termite control operators should under no circumstances be considered as a substitute for adequate informational and educational data to be made available generally to property owners, but should be a part of an informational program. A definite recognition on the part of the general public of the need for regulating structural-pests control operators should be encouraged; this matter should not be left solely to sponsorship by those especially interested or informed. Furthermore, licensing or certification should not create, through unreasonable demands for qualification, a group so specialized that a good practical operator would have no chance to qualify.

Necessarily, a tie-up should exist between regulation of structural-pests control operators and the agencies in authority best equipped to keep in touch with the work of such operators. This can be accomplished either locally, through ordinances, where proper facilities are available to enforce building code requirements, or through a centralized state agency associated with other important phases of the construction industry.

Especially should there be substantiating building regulations to prohibit the utilization by builders of termite-infested materials, in order that there be no new infestations established, and to preclude the re-establishment of infestation in areas where competent control or eradication work has been accomplished.

The cooperation of entomological or termite specialists in determining the knowledge which should be available to a structural-pests control operator is highly desirable, but primarily for consultation purposes and not as the final authority for the supervision of an operator's work. There should be ample authority for those who supervise the work of termite control operators to enter premises where properly qualified men are engaged, in order to inspect the work performed.

The protection of property owners from unscrupulous termite control operators cannot attain its fullest value until those responsible for overseeing construction work are familiar with termites and their damage and, further, have an understanding of other pests likely to be found similarly located in structures, including other wood-boring insects and fungi.

The Termite Investigations Committee was asked to, and did assist in formulating a proposed state law for regulating the activities of persons engaged in repairing termite damage, and it is believed that such a law would be of much assistance in combating the termite problem. A brief outline of this suggested law, prepared by members of the California State Department of Agriculture, follows. It embodies some of the basic provisions desirable for the proper regulation of structural-pests control operators.

I. AN ACT TO REGULATE THE PRACTICE OF STRUCTURAL-PESTS CONTROL

The people of the State of .... do enact as follows:

Section 1. It is unlawful for any person, firm or corporation to engage in or offer to engage in the practice of structural-pests control or in any way to solicit or advertise such practice without first having obtained a certificate from the state board or department of .... as provided for in this act.

Section 2. Structural pests are defined for the purpose of this act as termites, other wood-boring insects, or any kind of fungus growth or plant growth which causes decay in structures or buildings or parts thereof. The practice of structural-pests control is hereby defined to be the inspection or treatment or prescribing any method of treatment for hire of soil, lumber, poles, structures, buildings, or parts thereof, for the purpose of preventing damage by structural pests or for the purpose of repairing damage done by structural pests.

Section 3. The state board or department of .... shall, upon application filed upon proper form from any person for himself or representing any firm or corporation, by examination determine the qualifications of the applicant, and if satisfied as a result of such examination that the applicant is qualified to engage in the practice of structural-pests control, shall issue a certificate so stating, which certificate shall be authority to engage in the practice of structural-pests control and shall be valid until the end of the fiscal year in which same is issued unless revoked as provided for in Section 5 of this act, and such certificate may be renewed annually by the state board or department of ....without further examination and shall be valid for the duration of the fiscal year for which said certificate is issued.

Section 4. Every person, firm or corporation holding a valid certificate to engage in the practice of structural-pests control shall, on or before the tenth of each month, forward to the state board or department of ...., on forms supplied by said board or department of ...., a report of all operations for the next preceding month, showing the location and owner of each property treated or prescribed for, treatment recommended or prescribed, the chemicals used, concentration and quantities thereof, the nature of the damage, the method of treatment, and the charges made for the services and labor performed or prescribed.

Section 5. Said board or department of .... shall prepare all necessary forms and prescribe all rules governing the examination of applicants, and shall adopt whatever rules or regulations are necessary in the carrying out of the provisions of this act.

(*Optional Provision.* Each application for examination must be accompanied by a fee of ten dollars. Each registered structural-pests control operator shall annually between the first and the thirtieth days of June of each year pay to the state board or department of .... a fee of five dollars for a renewal of his certificate for the fiscal year next following, and shall keep such certificate conspicuously posted in his office or place of business at all times. Failure, neglect, or refusal of any person who is a regularly certified structural-pests control operator to pay in advance before the first day of July of each year said renewal fee of five dollars during the time his certificate remains in force shall *ipso facto* work a forfeiture of his certificate, which shall not be restored except upon a written application therefor and the payment to said board or department of .... of the sum of ten dollars, in addition to all delinquent annual certification fees, except that such person shall not be required to submit to any examination.)

Any certificate issued under the provisions of this act may be revoked or further certification refused by said board or department for failure to make reports, as hereinabove provided, for improper methods or for other cause sufficient in the opinion of the board or department to justify such revocation or refusal.

Section 6. The state board or department of .... and its duly authorized agents are hereby vested with full power to investigate the work of all persons, firms, and corporations engaging in the practice of structural-pests control and to require reports relative to the work in which they are engaged under the authority of the certificate issued them by the state board or department of .... Said board or department of ...., through its duly authorized agents, is empowered to enter premises, buildings, or structures, either completed or in the course of construction, for the purpose of determining whether or not persons who hold certificates to engage in the practice of structural-pests control are engaging in this practice in a suitable manner.

Section 7. There shall be paid by each person, firm, or corporation holding a certificate to engage in the practice of structural-pests control, to the state board or department of ...., each month fees in the amount of one per cent of the charges reported by them on the monthly reports submitted to said board or department of .... and as required by this act.

Section 8. All moneys received by the state board or department of .... under the provisions of this act shall be paid into the state treasury and be credited to the structural-pests control fund, which fund is hereby created (or into the state board or department of .... fund for structural-pests control purposes, which fund is by chapter .... Statutes of .... created) and shall be expended for the purpose of administering the provisions of this act under the administration of the state board or department of ....

Section 9. Any person, firm, or corporation violating any of the provisions of this act or violating the provisions of any lawful regulation promulgated under its authority shall be guilty of a misdemeanor.

QUARANTINE

Since termites must depend for their existence upon the utilization of cellulose for food, a wide variety of commodities consisting of wood are indicated as harborages, or possible carriers, for this group of insects. Consequently, wood materials, especially logs, lumber, furniture, heavy packing cases, ties, construction timbers, bracings in cars and vessels, etc., which are handled or transported by numerous agencies, present an enormous problem for regulation.

The value of quarantine measures in this case would rest primarily in the opportunity to specify for restriction a definite group of commodities handled through clearly defined transportation channels. Obviously, wood in its many forms is moved by countless agencies and carriers over which no reasonable control could be afforded. Inspection of wood commodities wherever found, in order to determine the possible presence therein of termites, would have to be depended upon. Under such circumstances, an inspection force exceeding all expectation would be required. Since the termite species liable to be encountered in interstate and intrastate commerce are likely to be native ones, a high degree of specialization would be necessary on the part of the inspection force, which fact presents considerable difficulty.

This indicates an impracticability in the utilization of quarantine procedure of a specific type to prevent the introduction or distribution of termites. If there is any other recourse to restriction, through state laws, it would probably be to place in the hands of a properly constituted authority the power to require the holding and destruction, or the treatment of termite-infested material offered for transportation, likely to be transported, or in the course of transportation, wherever it might be found or located. Such authority logically should be placed in the hands of officials associated with building and construction work, and not solely in the hands of an agricultural enforcement group whose specific duty is to prevent the introduction and spread of strictly agricultural pests. However, should any group of termites become a specifically agricultural pest, and should distinctly agricultural commodities serve as carriers or become affected thereby, they would automatically be amenable to the provisions of the agricultural statutes and regulations now in effect.

Furthermore, some agency, preferably a centralized one, could be made responsible for the issuance of permits for the movement of termite-infested material, under proper safeguards, to places for treatment, in the event that a treatment might be substituted for destruction. Living termites, unless of an innocuous species, should not be transported from one place to another except for scientific purposes, and then only when properly safeguarded.

In summary, it evidently becomes impracticable to utilize a quarantine regulation of the specific type characteristic for plant and animal pests and diseases, to prevent the introduction and distribution of termites, unless such measure be directed against one particularly destructive species, and even then only when relatively few specific commodities need be restricted. To attempt adequately to prevent with quarantine measures the introduction of termites would too deeply affect all commercial intercourse.

III. FEDERAL QUARANTINE LAWS

BY

THOMAS E. SNYDER

We have no definite proof that any exotic species of termite has been introduced and has become established in continental United States. One of our commonest species in eastern United States, *Reticulitermes flavipes* Kol., also is rather commonly distributed in Mediterranean Europe, and the common species of Mediterranean Europe, *Reticulitermes lucifugus* Rossi, was found in 1918 to occur in the vicinity of the Arnold Arboretum near Boston, Massachusetts. Much study of these species is necessary before it can be determined what their complete geographical distribution may be.

Another termite, *Cryptotermes brevis* Walker, which commonly damages the woodwork of buildings and furniture in the West Indies, Mexico, and Central and South America, has recently attracted attention in southern Florida, where it has damaged furniture and the woodwork of buildings in Key West, Miami, Palm Beach, and Tampa. It has been active, also, in New Orleans, Louisiana. It was first found in 1918 at Key West, Florida, by a federal quarantine inspector. *Cr. brevis* has also been found in a building at Durban, South Africa. This termite is not so injurious as the subterranean species of *Reticulitermes,* since it does not rapidly weaken buildings structurally.

Federal and state quarantine inspections have, from time to time, intercepted termites in shipments of material from foreign countries, and it is such careful inspection and certain restrictions on shipments that we believe will safeguard this country from the introduction of exotic termites.

The only federal quarantine in which termites are specifically mentioned and quarantined against is Quarantine No. 60 (Domestic) which became effective March 1, 1926. This quarantine forbids the shipment of plants with soil about their roots from the territories of Porto Rico and Hawaii to the mainland of the United States. Nearly seven years before, however, Quarantine No. 37 (Foreign) provided the same protection in the case of nursery stock, plants, and seeds shipped to the United States from foreign countries. Since June 1, 1919 shipments of such nursery stock, plants, etc., have not been permitted entry unless free from soil. The only exception to this practice is in the case of certain bulbs, seeds and nuts, which may be packed in sterile soil. In addition to this, it is the general policy of those responsible for the enforcement of Federal Plant Quarantine to require all plant products such as fruits, vegetables, etc., which are entered under permits from foreign countries, to be free from soil. Copies of Quarantines Nos. 60 and 37 may be secured by writing to the Plant Quarantine and Control Administration, Washington, D. C.*

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* The information regarding Federal Quarantine was supplied by the Plant Quarantine and Control Administration.

In the course of inspection of ships' cargoes, stores, etc., inspectors may occasionally find termites in lumber or other products not covered by Federal Quarantine. On these limited occasions experience has shown that shipping agencies, importers, and others willingly cooperate and take such steps as are necessary to safeguard the country from infestation by these pests.

Local or state quarantine authorities or individual citizens can cooperate with the Federal Government by reporting promptly to the Plant Quarantine and Control Administration or the Federal Bureau of Entomology any case of unusual termite damage or the occurrence of any unusual specimens of termites.

CHAPTER 55

PREVENTION OF WOOD DECAY IN BUILDINGS

BY

REGINALD H. COLLEY

In the great majority of cases it is cheaper to prevent decay than to repair or replace the rotted timber. Unsatisfactory service from wood in buildings is very often directly traceable to a lack of appreciation of the conditions that favor decay. To understand these conditions the architect, builder, and owner need to know only a few basic facts.

Decay is caused by fungi which grow on and in wood and destroy the wood substances as they grow. Generally speaking, the most important factor limiting their growth is moisture. However, temperature also affects the rate of growth, and consequently the rapidity of their destructive action. They are slowed up or stopped as the thermometer drops toward the freezing point, and they are killed by high temperatures. But they cannot grow at all, no matter how favorable the temperature, unless the moisture content of the wood is suitable for their development. Dry wood will not decay. Wood is food material for fungi, but they cannot use the food unless it contains at least 15 to 20 per cent of its weight in water. On the other hand, they cannot use the food when water is present in excess, that is, when the wood is thoroughly soaked through or is submerged in water. The latter conditions are found only under exceptional circumstances, for example, in piling which is driven below water level, and therefore need not be considered so far as ordinary buildings are concerned. The conditions most favorable for decay occur when the moisture content is somewhat above 20 per cent, and somewhat under the complete saturation point.

Certain chemicals, like creosote, zinc chloride, sodium fluoride, and bichloride of mercury, for example, protect the wood from decay even when there is enough moisture present to favor fungus growth. The simplest explanation of the action of such preservatives is that they poison the fungused wood.

With these facts in mind the principles of decay prevention can be reduced to the following general rule: To prevent decay, control the moisture content of the wood, or, if the conditions of use are such that moisture content cannot be controlled, use wood treated with a suitable preservative.

Infestation may and often does take place before wood is ever placed in a building, either through fungus spores that are always floating in the air, or because the lumber has been carelessly stored on the ground, under leaky sheds, or in direct contact with decaying timbers. After wood has been built into a structure infestation may result from contact with dirt or rubbish, with moist foundation walls or basement floors, or even with the ground itself. Water from leaky roofs, walls, window frames, rain spouts, or plumbing fixtures may not only carry the infestation, but also make conditions just right for rapid growth of the organisms.

Certain of the more destructive building-rot fungi in the United States form conducting strands which run from the ground up supporting columns or basement walls to the sills and timbers of the ground floor. These conducting strands carry water from the soil and, as a result, wood that was reasonably dry when installed may be supplied with moisture sufficient to keep the fungus growing.

The architect and builder should take every reasonable precaution to prevent infested material from getting into any permanent construction. This is not a simple task, because the recognition of the earliest stages of decay is nearly always extremely difficult, and often it is impossible. The best practical safeguard is a specification which calls for *properly dried lumber*. In any case, the wood should be allowed to dry before it is sealed in, in order to stop the growth of any fungi that may be present.

After the building is up the duty of keeping the wood dry falls on the owner or tenant. The architect should plan and the builder should construct so that it will be practicable for the owner or tenant to do his part. Any construction which favors the absorption or retention of moisture by wood should, therefore, be regarded as bad practice. Under such practice the wood does not have a fair chance to give the service that the owner feels he has a right to expect from it. For example, it is bad practice to lay a wood floor directly over a brick, cinder, or a concrete basement floor, because the wood may absorb sufficient moisture to bring about rapid decay. If a wood floor must be so laid the floor sleepers should be treated with a preservative. In addition, to secure maximum service, the ground should be provided with adequate drainage, the concrete or other base should be waterproofed, and in some cases the sleepers should be set so that the wood floor is raised several inches above the surface of its foundation. Thorough provision should be made for draining and ventilating the air space under the wood.

Oiling or painting floors before the wood is dry is very likely to lead to rot. Covering damp wood with oilcloth or linoleum will frequently bring about the same result. In both cases the decay is due to the retention of moisture, which favors the growth of fungi.

Cold water pipes should never be installed in such a way that the water which condenses on their surfaces drips or runs on to adjacent wooden framing or supports.

Building-rot fungi grow best in damp, stagnant air. It follows that good practice forbids the complete enclosure of the spaces under porches or under other floors that are built over unexcavated ground. Provision should be made for adequate ventilation. The same applies to basements in general. It would be well, in addition, to make sure that the basements and the spaces under the floors are thoroughly drained.

All of the preceding suggestions are based on the principle that if the wood used is reasonably dry, and if it is kept dry, it cannot decay. If these facts are clearly recognized by architects and contractors many of the present building-rot problems will soon cease to exist. However, there will always be some cases where treated wood should be used. Under certain conditions of service it will be practically impossible to keep the wood dry. Foundation timbers laid directly on the ground, and roof planks for use in industrial plants where the humidity is purposely kept high, may serve as examples. Such foundation timbers should be treated, because they may be wet a great part of the year. In cool weather moisture condenses from the humid air in industrial establishments and collects on the under side of the roof planks. The water is absorbed by the wood, and conditions favoring decay are set up. This roof problem may be partially solved by any one of several methods: (1) by insulating the outside of the roof against atmospheric temperature in order to reduce the condensation on the under side of the boards; (2) by the use of only the most durable woods; (3) by installing a battery of steam pipes near the roof to keep the roof planks drier; or (4) by the use of treated wood.

In repair work the contractor is faced with two important tasks: the replacement of the decayed wood with sound material, and the remedying of the conditions that led to the decay. Usually the wood is infested for anywhere from a few inches to two or three feet beyond the point where the rot appears. When such wood is removed, therefore, it is a good plan to cut out for at least a foot or two beyond the rotten areas, in so far as this is practicable. New, clean, untreated lumber should never be nailed against old, infested material, since this exposes the new wood to immediate attack, with the result that decay may be very much more rapid than in the case of the original wood. The conditions that favored the decay will most frequently be found to be connected in some way with damp foundation walls, damp basement floors, seepage water, or leaks. Leaks, of course, should be repaired promptly. Increased drainage and better ventilation may be necessary to remedy other faulty conditions.

Foundation walls and posts and the unexcavated ground under porches, or under parts of the house proper, can temporarily be rendered sterile, as far as wood-destroying fungi are concerned, by applying effective wood-preserving chemicals with an ordinary garden spraying outfit. The wood around the area which is being repaired can be treated in a similar manner, or by painting on the preservative with a brush. Such treatment would be effective only when used on uninfested wood. Local conditions will determine how often the treatment should be repeated. Where the odor is not objectionable, creosote will be found suitable for either spraying or brushing. A 5 per cent solution of zinc chloride, made by mixing 5 pounds of the chemical with 11½ gallons of water, or a 4 per cent solution of sodium fluoride, can be used in place of creosote. In the case of wood, however, it should be remembered that the chemicals applied to the surface do not reach the interior of the wood, and they therefore cannot kill fungi which have worked their way well into the lumber. Where the decay hazard is great, either the most durable of woods or well treated material should be used on the repair job. In any event, the general rule for decay prevention set forth in the early part of this article holds good —either control the moisture content of the wood or use treated wood.

CHAPTER 56

TERMITES AS A FACTOR IN EARTHQUAKE DAMAGE

BY

WALTER T. STEILBERG

In a report on the great San Francisco earthquake of 1906 Professor Charles Derleth, Jr., (1907) stated that:

> Properly constructed wooden buildings withstood the earthquake with the exception of their brick chimneys, no matter where located in the earthquake belt, except on the fault line and in regions of the greatest disturbance on soft ground. Some frame buildings collapsed upon favorable ground due to improper underpinning. There should be more continuity in the frames of wooden buildings, especially at the floor levels, and the underpinning should be more carefully attended to in the future.

In a report on the Santa Barbara earthquake of 1925 Professor Arthur C. Alvarez (1925) stated that:

> Timber frame buildings, whether covered with wood rustic or stucco, stood well, except where the bracing of the underpinning was weak due either to original inadequacy or subsequent decay. Where necessary, additional bracing in this vital region would be inexpensive and would be excellent earthquake insurance.

The low rates on earthquake insurance for frame dwellings also indicate that the 1906 and 1925 disasters gave evidence that wood frame construction is especially well adapted to withstand earthquake shock. The rates on earthquake insurance of the Board of Underwriters of the Pacific, effective September, 1931, establish the cost of insuring "frame dwellings and other frame buildings excluding all buildings with masonry veneer (not stucco) located on firm natural ground, and not exceeding three stories in height or 3,000 square feet ground floor area," as fifteen to thirty cents per hundred dollars of insured value, the exact rate depending upon the zone in which the structure is located. For each zone, however, the rate on such frame dwellings is less than two-thirds of that for the next lowest classification, namely, structural steel frame with monolithic reinforced concrete walls and floors.

The extensive damage to frame dwellings in the earthquake of March 10, 1933 at Long Beach and Compton, California, indicates that these favorable opinions of wood construction may now require some revision, or, at any rate, much more emphasis upon the quality of the construction and its protection from decay.

In a special edition of the Long Beach Sun, dated Saturday, April 29, 1933 and entitled *The Truth About Long Beach,* the following statement appears:

> The engineer making the minimum estimate arrives at his figures as follows: small homes, 10,000 [homes]; average damage, $150.00; $1,500,000 [= total damage].

It should be noted that this is offered as a *minimum* estimate, and that it has not been the policy of newspapers in any stricken area to exaggerate the earthquake damage in that region. Not all of the buildings received damage of such seriousness as to endanger life or even cause bad injuries; and the fact that not more than several dozen of them were demolished beyond repair is a remarkable tribute to the natural fitness of wood as a building material in a country subject to seismic disturbances, *provided* that such shocks are not followed by conflagrations. No exact count was made of the number of frame buildings which were thrown off their foundations; but the writer, who spent several weeks in making a general study of the behavior of structures in the affected zone, is of the opinion that there were two or three hundred cases of this type of damage in Long Beach and Compton. The Long Beach Building Department considered this opinion very conservative.

That the damage to wooden buildings at Long Beach was proportionately far greater than at Santa Barbara, which, according to the Carnegie Seismological Laboratory, suffered an earthquake of about the same intensity, is probably due to more than one cause. The ground condition is not so very different; nor was the standard of framing methods at Santa Barbara notably better; but the lumber used in the Los Angeles region is probably about the greenest that can be found outside of a forest—a condition which not only produced excessive shrinkage, tending to loosen nails and open joints, but which also made the buildings much more subject to attack of termites and fungi (chap 55). Of about fifty seriously damaged wooden buildings which were examined by the writer, twenty-four showed definite traces of termite infestation. Several builders who were making repairs to the overthrown bungalows advised the writer that every building that they had examined or worked on showed some termite damage. Usually the damage was caused by termites of the subterranean type eating the ends of the underpinning at their bearing on the mudsill, thereby destroying the holding power of the nails. In every case examined by the writer the structures were pushed off their mudsills by the earthquake shock—not off the foundation, as has been commonly reported. In only two of these cases was there any extensive destruction of the redwood mudsill. It is significant that the Long Beach Building Department found that none of the houses which had been repaired and "termite-proofed" before the earthquake by the companies engaged in such work showed serious damage; the services of these companies, however, often included a general improvement of subfloor construction, as well as the removal of lumber attacked by termites.

It must be admitted that a great many of the damaged houses had very poorly braced 2 inch × 4 inch underpinning, and would have fallen without the help of termites. Many were entirely lacking in ventilation of the underfloor space, and were weakened by dry-rot fungus. In this connection, however, it should be noted that the inspections of the Long Beach Building Department tend to support the opinion of the Department of Zoology of the University of California that dry-rot fungus and subterranean termites are usually associated, either because of some interdependence or because both the animal and plant pests thrive in the same environment (chaps. 1 and 9). In examining the earthquake effects suffered by a structure of any type it is very difficult to separate the many factors involved and to say definitely that any one factor is responsible for any certain proportion of damage. Obviously, this statement also applies to the termite factor in damage to wooden buildings; it would be very difficult to *prove* that any considerable number of the failures of frame buildings at Long Beach would not have occurred had they not been previously injured by termites. On the other hand, there seems to be no doubt that termites and dry rot contributed no small part to the unprecedented damage to frame buildings that was one of the most notable results of the Long Beach earthquake.

The termites which contributed to the damage to frame buildings in the Long Beach earthquake were evidently of the subterranean type; the dry-wood and damp-wood termites may have also had a part, but the writer saw no definite traces of their work. Subterranean termite attack is usually most serious near the ground, and it is in this region that the average frame dwelling is most severely stressed in a shock. Nevertheless, the other types of termites might also cause damage which would so weaken a structure as to contribute to its collapse or serious injury in a severe earthquake.

Within the last two years, serious infestations of the large damp-wood termites have been found in several of the Oakland wharves, attacking the girders and deck planking; an earthquake would obviously be more likely to cause damage to such a pier than to a sound structure.

Dry-wood termites have as yet caused relatively little damage in California, but our knowledge of their activities is increasing. Since these insects do not require the ground connection that is vital to the subterranean variety, they present another type of hazard to wood structures. Their attack may come through inadequately screened ventilators of roof spaces, through shingling or clapboarding, or through the dried-out tar paper and sheathing under roof tiles. In much wood framing, the roof space, like the subfloor space, is practically closed to inspection; once infested, the destruction of truss members, rafters, sheathing, and ceiling joists could go on for years without being discovered. It is just such hidden weaknesses of a building, that an earthquake seeks out. Obviously it would be very difficult to exclude the dry-wood termite, if prevalent, from such vulnerable regions of the structure; the only sure protection would be the use of lumber of an unpalatable variety or treated lumber in those limited areas infested by the dry-wood termite. Fortunately, much roof space construction, such as truss members, purlins, rafters, and ceiling joists, can easily be cut to length before treatment; in the case of standardized roof constructions, such as the Lamella roof and "Summerbell" trusses, the stocking of treated members should involve little additional expense. By their rocking motion, earthquakes test the joints of buildings; and the joinings of wooden members seem to be especially inviting to termites. They habitually live in narrow galleries and passageways, and it is in such cracks and crevices that they find the more open end grain of the wood, the tears and abrasions of nailing, and the damper and softer wood surfaces; it is in such places that subterranean termites start their work, and dry-wood and damp-wood termites start their colonies.

Long Beach and Compton, California, are built on practically level ground, and the first floors of the houses are in most cases not more than three feet above the foundations. When the underpinning of these buildings failed, they were thrown sidewise and dropped about two or three feet, as indicated in some of the accompanying illustrations (fig. 181). In a few rare instances the frames partly collapsed, and in at least two cases the second story framing parted from the first story framing in the same way that the underpinning pulled loose from the mudsill, very probably due to termite damage—whether subterranean termites that had traveled up in their tunnels from the earth was not determined. Many people were injured when these houses were thrown to the ground, but none, so far as could be learned, were killed. The damage, as has been indicated, amounted to millions but was not large, proportionately, for each dwelling, being on an average less than 5 per cent of the construction cost.

Had these cities been built on hillsides, like many sections of the cities of the San Francisco Bay region, the destruction to property and the loss of life might have been very serious. It is easy to realize that a building falling over on a steep slope is very likely to collapse, even though well constructed; furthermore, such demolition would enormously increase the conflagration hazard. It should be noted in this connection that hillside dwellings are peculiarly subject to termite attack, because it so often happens that earth is piled up against the outside of the building, on the uphill side, above the line of the foundation, thus keeping the adjacent mudsill, underpinning, and joists damp and soft—just the sort of wood that appeals to the appetite of termites. Furthermore, the temperature of the earth and of the subfloor space on this side of the building is likely to be somewhat warmer and less variable and therefore favorable to termite activities (chap. 2, p. 16). Special care should therefore be exercised in constructing hillside houses, to see that there is no such exposure of the underpinning and sills to dampness. Figure 182 indicates the proper foundation construction for hillside foundation walls.

On sloping sites in a country subject to earthquakes it is advisable not only to keep all wood well away from ground contacts or ground moisture, but also to further protect all subfloor construction, such as mudsills, underpinning, posts, girders, plates, first floor joists, subflooring, and sheathing, within two feet of the ground by the use of (1) creosote-impregnated lumber, or (2) high grade heart redwood having a high percentage of the extractive, which is the material's natural protection against insect attack, for mudsills, pier caps and all members in direct contact with masonry. Pressure treatment has been found far more effective than brush coatings with any of the creosote preparations now on the market (chap. 41). Pressure-treated lumber containing not less than 8 pounds of creosote per cubic foot, and showing a minimum penetration of $\frac{3}{16}$ inch for the 1-inch and 2-inch thicknesses should, therefore, be used wherever first class protection is required. If pressure-treated lumber is not available, the minimum protection of this part of the

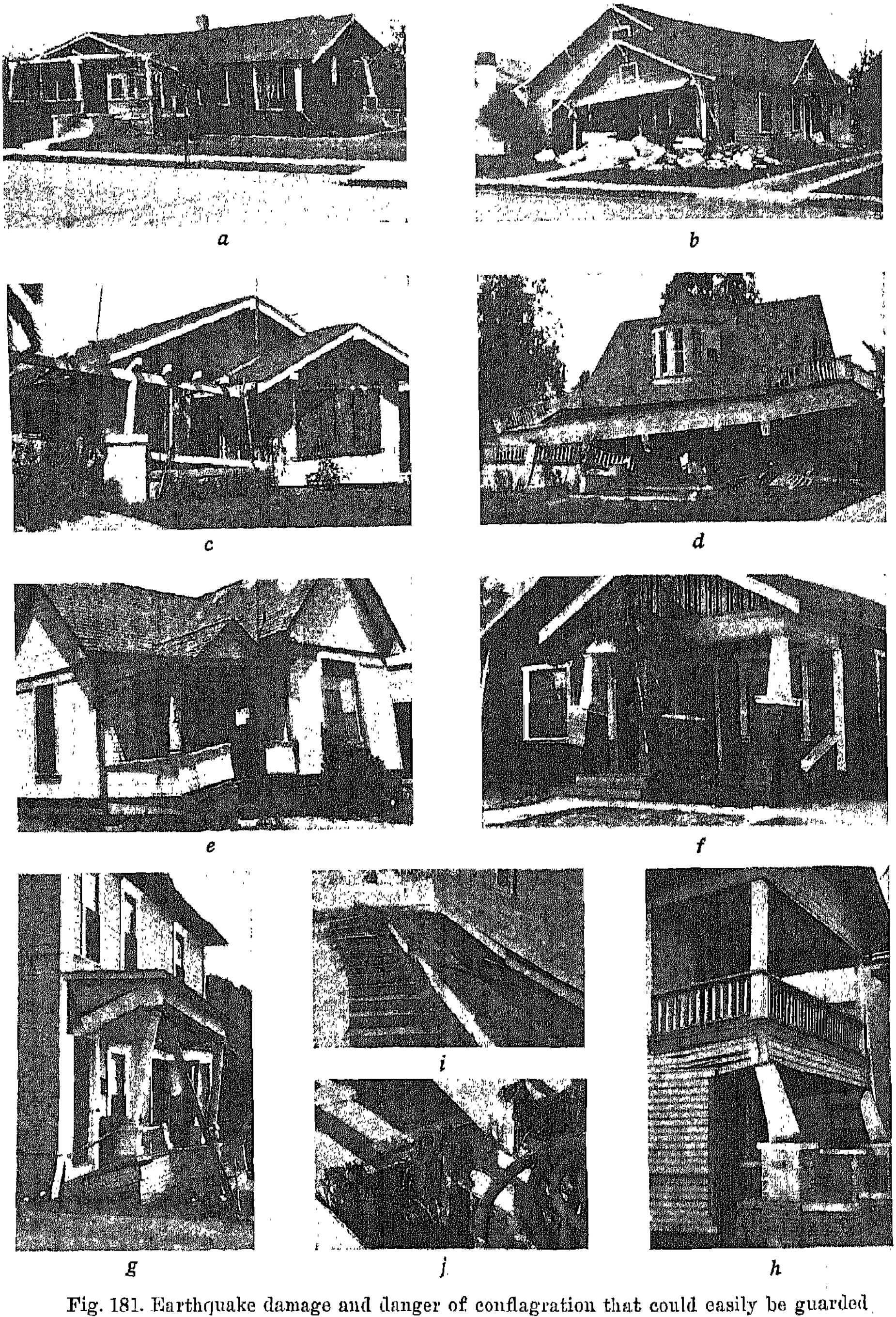
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Fig. 181. Earthquake damage and danger of conflagration that could easily be guarded against.

(Concluded on bottom of page 721)

frame should consist of a mudsill of No. 1 heart common redwood, painted with two coats of refined creosote. The ends of the underpinning, first floor joists, posts, and all other wood members within one foot of the ground or in direct contact with masonry should have the same brush treatment. When pressure-treated lumber is used, it is also necessary to double-brush-coat any surfaces that have been cut after treatment. Obviously, the ideal procedure would be to cut the lumber to lengths before treatment, but this is not always practicable.

Special attention should also be given to the bracing of the underpinning of hillside houses subject to earthquakes; and in many cases it is advisable to introduce angle-braces spiked to the sides of the joists and underpinning. As indicated in Professor Derleth's report on the San Francisco earthquake, "there should be more continuity in the frames of wooden buildings," especially on hillsides. Diagonal sheathing and cement stucco form a strong vertical tie across the floor systems. Balloon framing is better than platform framing, provided that shrinkage differences can be nullified by using seasoned joists, girders, and plates; but when balloon framing is used special care should be taken to tightly fit in 2-inch creosoted bridging at the first floor line to hinder access of termites to the upper parts of the structure.

There is also a tendency in hillside houses to omit the ventilators for the subfloor space, especially on the upper side of the building where they are most needed to provide cross circulation of air and to dry out the dampness that will otherwise occur in this part of the building. Ventilators for the subfloor space should be ample. If the ground is covered with rat-proofing, as specified below, minimum requirements may be taken as 1 square foot net area of vent for every 300 square feet of plan area; and, if the earth is left uncovered, there should be 1 square foot net area of vent for every 100 square feet of plan area. Where such vents are close to the ground and are likely to be concealed by shrubbery, so that termites might build their tunnels across the outer face of the wall and through the ventilators, they should be provided with bronze mosquito screening (the mesh of the ordinary fly screening is not fine enough to exclude termites). If the ground levels on the upper side of the building prevent the placing of vents directly through the wall, ducts such as are used in warm air heating should be carried up in the wall to the necessary height.

One of the best preventives of termite attack on hillside houses is the provision of ample drainage for the foundation and basement walls, especially on the upper side of the building where water from the slope above might accumulate. One of the best methods to accomplish wall drainage is to use a layer of 4-inch burned clay partition-tile, laid without mortar, against the asphalted outer face of the wall before back filling—the cells of the bottom

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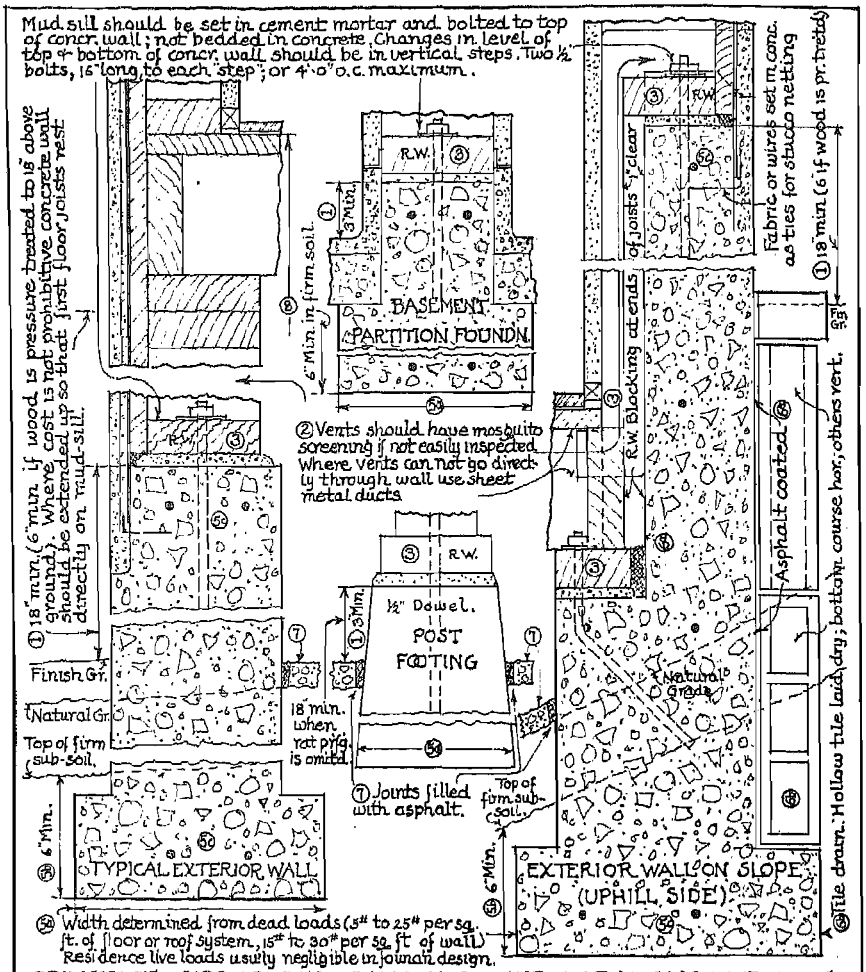
a–h. Typical examples of serious damage to frame dwellings at Long Beach and Compton, California, in the earthquake of March 10, 1933. There were several hundred cases of this kind, and several thousand that were less serious. Many of these failures were in part due to termite damage to underpinning, as shown in details *i–j*. Proper construction and protection (chaps. 46, 48) would have prevented all but minor damage at relatively small expense.


R.W.
③
① 3"Min.
⑧ 6"Min. in firm soil
BASEMENT PARTITION FOUNDN.
(5a)
①18" min. (6" min. if wood is pressure treated to 18" above ground). Where cost is not prohibitive concrete wall should be extended up so that first floor joists rest directly on mud-sill.
Finish Gr.
Natural Gr.
Top of firm sub-soil.
⑧ 6"Min.
TYPICAL EXTERIOR WALL
⑦
½" Dowel.
POST FOOTING
18" min. when rat prfg. is omitd.
Top of firm sub-soil.
⑦ Joints filled with asphalt.
of joists 1" clear
R.W. Blocking at ends
Fabric or wires set in conc. as ties for stucco netting
① 18" min. (6 if wood is pr. treatd)
Fin. Gr.
Asphalt coated (6a)
Hollow tile laid dry; bottom course hor.; others vert.
(6b) Tile drain.
Natural Grade
(6b)
⑧
EXTERIOR WALL ON SLOPE (UPHILL SIDE)
⑧ 6"Min.

Mud sill should be set in cement mortar and bolted to top of concr. wall; not bedded in concrete. Changes in level of top & bottom of concr. wall should be in vertical steps. Two ½" bolts, 15" long, to each "step"; or 4'-0" o.c. maximum.

② Vents should have mosquito screening if not easily inspected. Where vents can not go directly through wall use sheet metal ducts.

(5a) Width determined from dead loads (5# to 25# per sq. ft. of floor or roof system, 15# to 30# per sq. ft of wall) Residence live loads usually negligible in foundation design.

PRINCIPLES OF PREVENTING DAMAGE BY SUBTERRANEAN TERMITES.

1. All wood not pressure-treated at least 18" above ground (press.-treated, 6" min.)
2. Space under 1st. fl. well ventilated (1 sq. ft. per 300 sq. ft. if ground is rat-proofed, 1 sq. ft. per 100 sq. ft. if ground surface is not sealed against dampness).
3. All wood in contact with masonry No 1 heart common red-wood, creosoted 2 coats or pressure treated (8# per cu. ft.) pine or fir. For best protection use pres. treatd. red wood. Cut ends of treatd. or coatd. lumber & all other lumber within 6" of masonry creosoted 2 coats.
4. All concrete forms & other wood rubbish removed from space under floor.
5. Foundation cracks restricted to minimum by (a) proportioning to actual loads, (b) extending at least 6" into sub-soil, and (c) reinforcing top & bottom (2-¼" os, top; 2-¼" os botm., min. reinforcg)
6. Foundation protected from dampness by (a) asphalt coatg. (preferbly asbestos fibred asphalt) and (b) by tile drains; (preferably in the form of a veneer of (3" to 6") partition tile, laid dry.
7. Ground surface under floor sealed with rat-proofg (1½" cem. concrete asphalted, or asphalt conc.)
8. Where absolute protection is required (by value of super-structure, inaccessibility for inspection, seriousness of termite hazard), all wood below 1st. fl., or within 18" of ground should be pres. treated.

{1 to 5 are essentials of good frame construction; 6 to 8 are additional requisites of the very best work. (e.g.-fine residences, schools, and public buildings)

Fig. 182. Architectural details presenting methods in use for structural prevention of attack by subterranean termites. Original after W. T. Steilberg.

tier horizontal, of the other tiers vertical—thus providing air space between the earth and the face of the wall.

Termites often effect entrance to a wooden structure by way of the uncovered ground in the under-floor space, as well as from the outside of the building. This fact makes it highly desirable to use what is commonly known as rat-proofing, a thin layer of concrete spread over the surface of the ground that is not otherwise covered by concrete flooring. Most of the rat-proofing that has been used is material of a rather inferior quality in a very wet mix and therefore likely to shrink away from the foundation at the edges, or to crack. While still effective as a barrier to rats, it is not a sure protection against termites, which will find their way through any but very small cracks.

Rat-proofing, to be effective as termite-proofing, should consist of a 2-inch layer of concrete composed of about one part of standard Portland cement to three of sand, to five of crushed rock, preferably crushed limestone or trap rock, since these materials produce concrete which has a much smaller shrinkage coefficient than other aggregates, such as gravel or sandstone. As little water should be used as is practicable to make a workable mix, not more than six gallons (including the water in the sand) to the sack of cement. The earth on which this rat- and termite-proofing is to be spread should be well wet down and tamped, and the concrete itself should be well tamped after being spread over the ground. It should be kept wet or at least damp for several days to assure proper curing. A heavy brush or, better, a "spreader" coat of emulsified asphalt will serve this purpose and will also help to keep ground moisture out of the subfloor space. If the area on which the rat-proofing is to be used is larger than about 100 square feet, it would be well to subdivide it with ¾-inch shrinkage joints at about 10-foot intervals, and also to provide a shrinkage joint along the foundation; these shrinkage joints should afterwards be carefully filled with hot asphalt. It is possible that an asphalt emulsion rat-proofing, resembling the paving now used on tennis courts, may be developed which will be as inexpensive as the Portland cement concrete described above, and will have the advantage of being less likely to crack and also of being more resistant to the intrusion of ground dampness. Building owners should realize that in using either Portland cement concrete or emulsified asphalt concrete as rat-proofing they not only protect their houses from rats and termites, but also exclude much ground dampness, which is a very considerable factor in the cost of heating and in causing the warping of floors, doors, and interior finish, and the odor of mustiness which is often present in basements, cellars, and lower stories.

A usual sequel to serious earthquake damage is a conflagration. This happened not only in the largely wood-built cities of San Francisco and Tokio, but also in some of the Italian cities that were destroyed by earthquakes. Santa Barbara and Long Beach were fortunate in not having fires that got beyond control. The cities affected by the 1933 earthquake were especially fortunate in that the grave conflagration hazard created by the overthrow or displacement of hundreds of wooden buildings did not materialize. The fact that the gas and electricity, and the oil in electrically driven burners, which were used almost exclusively for fuel in these houses, were instantly shut off at the source saved the southern California cities from damage which might have far exceeded the destructive effects of the earthquake itself, as was the case at San Francisco in 1906. California has been most fortunate not only in that the earthquakes of 1906, 1925, and 1933 occurred at favorable hours of the day, but also in that the two latter earthquakes were not in such localities or during such cold weather that there might have been many sources of fire other than the easily and centrally controlled gas and electricity. There are regions and there are weather conditions in the state in which wood and coal furnaces, stoves, and fireplaces are much used.

While the safety of the community as well as the investment of the owner are involved in the problem of protection against termite damage as it affects earthquake and conflagration hazards, it is highly probable that economic factors will for the present determine the extent to which protective measures are employed. It may, therefore, be of interest to indicate the approximate present costs of the several methods of protection that have been indicated above. Considering a 10 foot x 10 foot ground floor area as a unit of computation, the following prices are averaged from quotations by several Oakland and Berkeley contractors and material dealers:

a. Rat-proofing, as specified above	$ 6.00
b. Emulsified asphalt spreader-coat on rat-proofing	1.00
c. Pressure-tank treatment of mudsill underpinning (assumed 2 feet high), posts, first floor joists, bridging, bracing, subflooring, and sheathing 2 feet above ground, at $25 per M	15.00
d. Brush-coating cut ends of lumber	1.00
e. Facing one side of foundation wall with 4-inch partition tile (on one side of 10 feet x 10 feet unit)	1.50
	$24.50

This would indicate that the cost of a first class job of termite-proofing would add not more than $250 to the cost of an average residence of 1,000 square feet ground floor area. On a steep hillside the cost of parts of the structure would be somewhat higher. In this connection, it may be of interest to note that the cost of increasing the height of an 8-inch concrete wall by 6 inches is about 20 cents per lineal foot. It should be noted that the above estimate provides for an improvement of construction which not only provides termite protection, but also rat-proofing and the exclusion of ground moisture from the building—the latter being a considerable factor in the cost of heating.

The estimate indicates that the pressure-treatment of the lumber is the largest item; next to this, the rat-proofing. In most houses as now constructed both of these protections are dispensed with, but there is no question of their ultimate economy for wood structures intended to last more than twenty years. For structures for which only a short use-life is intended, it will be good economy at least to extend the foundations well above the finished grade, and to use a pressure-impregnated mudsill or at least sinker redwood (chaps. 41, 42) well brushed with creosote, and to creosote the ends of the underpinning and other wood in direct contact with masonry. The cost of these precautions, including an increase of 6 inches in the height of foundation, would add not more than $50 to the cost of a house of about 1,000 square feet of ground area.

In the foregoing recommendations regarding foundation construction, rat-proofing, wall drainage, ventilation, and creosoting of subfloor timbers, there is little that is new; most of these measures have been, at least in principle, part of the standard practice of many architects and builders. Now, however, the possible sequence of termite damage, namely, earthquake damage and conflagration, gives a new importance to these practices of good construction. They are no longer merely economic measures for the individual to decide for himself; the welfare and safety of the community are also involved. Providence cannot always be depended upon to restrict the occurrence of earthquakes to weather conditions when the conflagration risk will be at a minimum, or to hours of the day when relatively few people will be exposed to falling débris. Italy and Japan have learned this lesson very thoroughly through the death and injury of several hundred thousands of their people. America, and California in particular, has had three warnings in the shape of "fortunate earthquakes," which have caused relatively few deaths, and in two instances have been followed by eras of great prosperity. The recent southern California earthquake was serious enough to make us realize that we can no longer trust to luck. There is no need for dismal predictions of disaster, but there is urgent need for public recognition of the earthquake menace and the requirement of good construction. Termites are working such increasing damage in the state that good construction must include proper protection from their attack.

The Long Beach earthquake indicated that termite damage prepares the way for earthquake damage, and may thereby prepare the way for a conflagration. It is entirely possible that an earthquake may prepare the way for termite damage. In the recent southern California disturbance, numerous cracks were found in the concrete, brickwork, and stucco of literally thousands of buildings which were otherwise not seriously injured. Such cracks, as has been indicated in other chapters of this book, provide termites with access to the wooden parts of the buildings and should be carefully repaired (chap. 48) to avoid future infestations.

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